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Movement of Tagged Dredged Sand at Thalweg Disposal Sites in the Upper Mississippi River

Volume 1: Gordon's Ferry and Whitney Island Sites

D. L. McCown, R. A. Paddock, and J. D. Ditmars

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FOREWORD

Argonne National Laboratory and the U.S. Army Corps of Engineers, Rock Island District, have undertaken a four-year investigation of main-channel, or thalweg, disposal of sand dredged during maintenance of the navigation channel in the Upper Mississippi River. During a routine dredging operation, hydraulically dredged sand was tagged with dyed sand and returned to the river channel downstream of the dredging site. The tagged dredged sand initially formed a pile along the thalweg of the river. Subsequent monitoring, which included taking surficial bottom samples and measuring bathymetry, was used to study the movement of the tagged sand in the river.

In a series of preliminary studies, Argonne evaluated alternative sampling and detection procedures for identifying tagged sand in the river environment. These preliminary studies were discussed in *Sampling and Detection of Tagged Dredged Material* (ANL/EES-TM-169), which was published in January 1982.

A full-scale experiment was first carried out in the fall of 1981 during a routine dredging operation at a site near Gordon's Ferry, about 23 km downstream of Dubuque, Iowa. Experience gained at this first site was used to refine the experimental procedures, and a second experiment was initiated at the Whitney Island site near Hannibal, Missouri, in the fall of 1982. The experimental procedures and the results from surveys at these first two sites through June 1983 are discussed in this report (ANL/EES-TM-270, Vol. 1).

A third experiment using a dyed-sand tracer was initiated at the Savanna Bay site near Savanna, Illinois, in the fall of 1983. In addition, bathymetric measurements were carried out at a fourth thalweg disposal site near Duck Creek, about 24 km upstream of the Savanna Bay site, to monitor changes in the physical structure of the disposal pile with time. The results from surveys over a nine-month period at these second two sites will be presented in ANL/EES-TM-270, Vol. 2. Results from additional surveys at Gordon's Ferry and Whitney Island through the fall of 1984, including results from the analysis of bottom cores taken at the Gordon's Ferry site during the summer of 1983, will be reported in ANL/EES-TM-270, Vol. 3.

ACKNOWLEDGMENTS

The authors acknowledge the valuable assistance of Conrad Tome of the Energy and Environmental Systems Division (EES) in carrying out the field experiments and in subsequent data analysis. Terri Jabon, formerly of EES, helped in the early stages of the experiment at Gordon's Ferry.

The support provided by the Rock Island District of the U.S. Army Corps of Engineers exceeded simply funding the project. Henry Pfiester, Chief of Operations, participated in formulating the initial experimental plans and saw to it that we had access to logistical support from the District. Project managers Stanley Ashmore and Richard Baker often joined us in the field and took time to understand our activities. The Survey Branch provided charts and established survey controls, and the Hydraulics Regulation Branch supplied the water level and flow data. Finally, the project would not have been possible without the assistance and patience of the Master and crew of the dredge *William A. Thompson* during the tagging operations.

The progress of this research was reviewed regularly by two units of the Great River Environmental Action Team: the River Resources Coordinating Team, chaired by Stanley Ashmore and later George Wells of the District, and the On-Site Inspection Team, chaired by Gail Peterson of the U.S. Fish and Wildlife Service. Their questions, comments, and support are appreciated.

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ABSTRACT

Experiments were conducted at two sites on the Upper Mississippi River to determine whether and how quickly hydraulically dredged sand would move away from a thalweg disposal site into sensitive habitat areas. Hydraulically dredged sand was tagged with sand coated with fluorescent dye before being deposited in the thalweg. Bathymetric surveys and surficial bottom sampling were conducted on several occasions within 588 and 249 days following disposal at the Gordon's Ferry and Whitney Island sites, respectively. Bottom samples were inspected under ultraviolet light to detect the presence of dyed sand.

At both sites, the evidence indicates that the tagged sand remained in the main channel and did not migrate into backwaters and sloughs. The topographically distinct features of each disposal pile were eradicated during the first occurrence of high flow after disposal. The bottom in the disposal area eventually took on the characteristics of the surrounding river bottom. At Gordon's Ferry no downstream movement of tagged sand occurred for over a year; at Whitney Island a major portion of the tagged sand moved downstream about 0.5 km within six months and about 0.8 km within 10 months. The differing rates of downstream movement were probably due to the relatively large flood experienced at the Whitney Island site, coupled with differences in the geometries of the two sites and the initial disposal piles.

1 INTRODUCTION

Argonne National Laboratory conducted two large-scale field experiments on the movement of tagged dredged sand after its disposal in the Upper Mississippi River as part of an ongoing study for the U.S. Army Corps of Engineers, Rock Island District. Hydraulically dredged sand was removed from the river during routine channel maintenance, tagged with dyed sand, and returned to the river channel downstream of the dredging site. The initial phases of the study are reported here.

1.1 BACKGROUND

The U.S. Army Corps of Engineers, Rock Island District, is investigating main-channel disposal as one option for disposing of uncontaminated sand dredged during maintenance of the nine-foot navigation channel in the Upper Mississippi River.[1] In this option, sand dredged from shallow, or shoal, areas of the channel is disposed of in deeper water at another location along the channel.[2] This disposal technique is also called thalweg disposal, because the thalweg is the line following the deepest part of the channel. Other disposal options include creating or nourishing beaches at the shoreline, piling sand on river islands, and placing sand in upland locations out of the floodplain.[3,4]

The costs, environmental impacts, and operational constraints associated with a particular disposal option depend greatly on the nature of both the dredging and disposal sites. Generalizations concerning the efficacy of a given technique are rarely possible. However, environmental concern regarding potential losses of aquatic and terrestrial habitat is common to all options. Main-channel disposal appears attractive to the Rock Island District in some instances because, in addition to low costs and minimal operational problems, habitat disruption may be small.

Because the dredged sand is introduced back into the river in deeper areas of the main channel, sensitive habitat regions (e.g., main-channel border areas, sloughs, and shallow backwaters) are not immediately modified. However, it is not known whether the dredged sand will remain in the thalweg or whether it will be transported out of the main channel into habitats of concern. No documented demonstration could be found of main-channel disposal in the Upper Mississippi River, or elsewhere, that provided information on this issue.

Concern about movement of dredged sand into sensitive habitats provided the initial impetus for this study. During the study, however, speculation arose as to whether main-channel habitats might not also be valuable at some sites. Thus, the residence time of dredged material in the original disposal location became an issue nearly equal in importance to that of movement of dredged sand out of the main channel into other sensitive areas.

In seeking ways to determine the postdisposal location of dredged sand in the Upper Mississippi River, the Rock Island District was investigating tagging the dredged sand with sand coated with fluorescent dye. Argonne assisted the District in evaluating alternative sampling and detection procedures for tagged sand. It developed and documented procedures for sampling surficial bottom sediments, detecting the presence of dyed sand in samples by onboard visual inspection in an ultraviolet light box, and photographing the ultraviolet-illuminated samples for further detailed analysis.[5] On the basis of small-scale field tests of those procedures, the Rock Island District and Argonne undertook the planning and execution of full-scale main-channel disposal experiments.

1.2 OBJECTIVES AND SCOPE OF THE EXPERIMENTS

The two experiments reported here were initiated about a year apart, with the initial results from the first experiment influencing the planning of the second.

Therefore, although the objectives and scope of each experiment are different in detail, the same general objectives and scope pertain to each.

The overriding objective of each experiment was to determine the locations of dredged sand in the river following thalweg disposal. This objective was addressed by tagging the dredged sand with dyed sand of similar size and shape during dredging and by subsequently sampling the surficial bottom sediments in the river to detect the dyed sand. The presence of dyed sand in river sediments implied the presence of dredged material. Detection of dyed sand in sensitive habitat areas (e.g., main-channel borders, sloughs, and backwaters) had priority throughout the study. Sampling after disposal focused on the disposal area and on downstream areas, including sensitive regions. Because sampling was limited to surficial bottom sediments at specific locations within the river, a mass balance for dyed sand was neither planned nor attempted.

During the early stages of the first experiment, observations of dyed sand in the samples were reported in qualitative terms like "dyed sand present" and "no dyed sand present." Measures of the amount of dyed sand in samples were instituted shortly thereafter as a means of reporting on the relative quantities of dyed sand. However, such quantitative statements do not imply a mass balance or concentration in the strict senses of those terms.

When it became apparent in each experiment that the dredged sand (as inferred from dyed sand locations and bathymetric measurements) did not disperse widely within a few days of disposal, greater emphasis was placed on delineating the disposal pile and measuring its subsequent modification. Interest in the behavior of the disposal pile required sampling at higher spatial resolution in the vicinity of the disposal area. Ecological concerns related to the residence time of dredged sand at the disposal site helped to drive this interest. In this way, dual measurement objectives were established: sensitive habitats away from the disposal site were monitored to determine whether dredged sand had reached them, and the disposal site itself was surveyed to determine changes in the original placement configuration.

1.3 GENERAL EXPERIMENTAL APPROACH

The Rock Island District, in consultation with Argonne, selected the sites for the main-channel disposal experiments based on its routine channel maintenance program and the suitability of the sites for thalweg disposal. Site suitability for main-channel disposal was governed primarily by the availability of a section of deep channel for disposal within a reasonable downstream distance of the dredging location and by proximity to side channels or backwaters.

To estimate dyed sand requirements and select an appropriate disposal location, the District estimated the size (volume) of the dredging cut on the basis of channel surveys made prior to dredging. However, the District then made detailed bathymetric surveys of the dredging and disposal areas immediately before the actual dredging began, and conditions encountered during dredging influenced the dredge cut. The need to modify earlier estimates of dredging volumes and specific locations was significant in both experiments. Consequently, dyed sand injection rates were determined just prior to initiation of dredging and were then adjusted to accommodate changes in dredging.

Prior to dredging Argonne used Corps of Engineers survey data and field markers to establish a coordinate system for the experiment. The coordinate system was checked in the field for consistency and applicability for future sampling and navigation. Argonne also measured the predredging bathymetry in the estimated disposal area and sampled surficial bottom sediments to confirm the absence of any dyed sand in the background. The Rock Island District prepared the dyed sand and delivered it to the dredge.

The hydraulically dredged sand was discharged directly through a downstream discharge pipeline or indirectly through a separate booster pump and discharge system. A disposal pile was created as the dredge and/or discharge pipeline moved upstream. During dredging Argonne directed and monitored the injection of dyed sand into the suction side of the hydraulic dredge pump. The location of the end of the discharge pipe was recorded at regular intervals throughout the dredging operation. During the second experiment, bathymetry was measured in the disposal area to assist in the placement of the dredged sand.

Shortly after dredging was completed, Argonne surveyed the disposal site and downstream areas. Bathymetric measurements were made in the disposal area to determine the physical size of the disposal pile or piles. Collection of surficial bottom samples at the disposal site and along downstream transects was accompanied by onboard observation of the samples to detect dyed sand grains. In addition to downstream transect locations, sample stations in slough and backwater areas were sampled. Sampling continued downstream from the disposal pile until transects were found from which samples showed no visual evidence of dyed sand. Subsequent surveys at the experimental sites were undertaken to gather information on the changes in the bathymetry of the pile and in the distribution of dyed sand in the surficial sediments. Navigation and plotting systems on the survey vessel permitted locating and returning to sample stations, with a resolution of a few meters.

1.4 EXPERIMENTAL SITES

A generalized map of the Upper Mississippi River, including the two experimental sites, is shown in Fig. 1.

1.4.1 Gordon's Ferry Site

The Gordon's Ferry experimental site is in Pool 12 about 12 km (7.7 mi) upstream from Lock and Dam 12 at Bellevue, Iowa, and about 23 km (14.3 mi) downstream from Dubuque, Iowa. As indicated in Fig. 2, the area dredged in October 1981 extended from about river mile 565.2 to mile 565.5 (measured from the confluence with the Ohio River), and the disposal area from about mile 564.6 to mile 564.9.

The reach in which the experiment was conducted is relatively straight, varying in width from 400 m (1300 ft) to 600 m (2000 ft). The Iowa bank is steep and rises abruptly in a railroad embankment revetted with rock. Downstream from the disposal area are six submerged wing dams along the Iowa shore. The Illinois side of the river is marked by lowlands cut through with sloughs and backwaters for at least 0.8 km (0.5 mi)

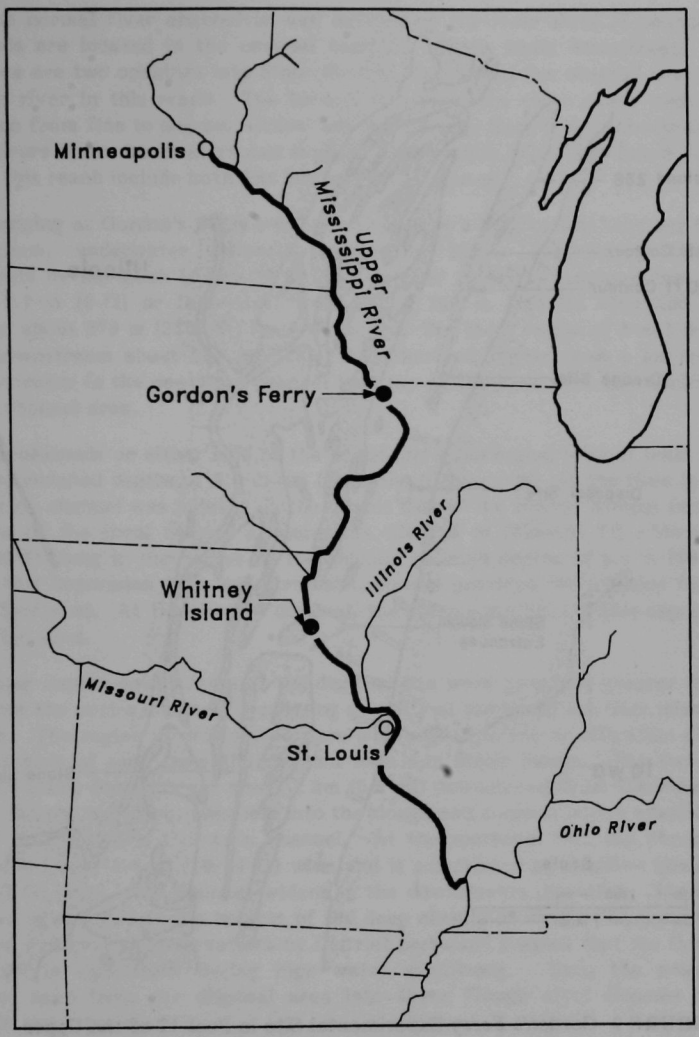

FIGURE 1 Location of Experimental Sites along the Upper Mississippi River

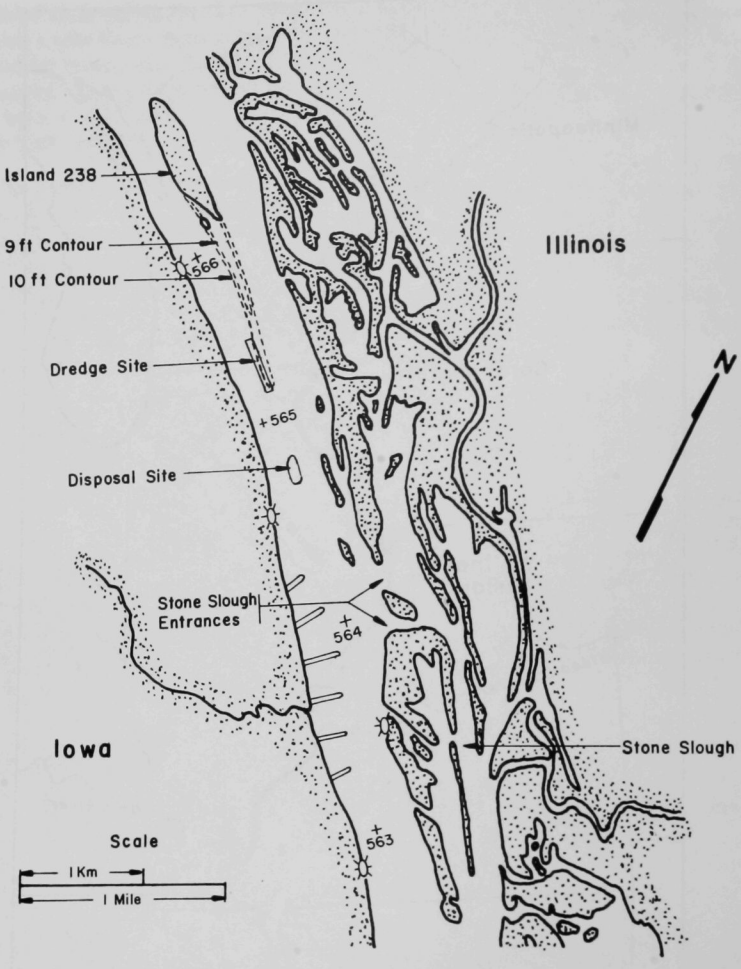

FIGURE 2 Gordon's Ferry Experimental Site in Pool 12 of the Upper Mississippi River

inland. The normal river channel is well defined by the river sides of islands. Three small islands are located in the channel near the Illinois bank; downstream from the disposal area are two openings into Stone Slough. The navigation channel is on the Iowa side of the river in this reach. The bottom sediments are clean sands that generally range in size from fine to coarse. Gravel has occasionally been found in bottom samples, and mud occurs in the backwaters and sloughs. The bottom conditions found in the main channel of this reach include both flat bed and dune regimes.

Dredging at Gordon's Ferry was necessitated by a longitudinal sand bar formed as a downstream, underwater extension of Island 238. Predredging bathymetric measurements by the Rock Island District on October 15, 1981, indicated that the shoal region of 2.7-m (9-ft) or less depth* was about 100 m (330 ft) wide and extended downstream about 975 m (3200 ft) from the island. The shoal region of 3-m (10-ft) depth extended downstream about 360 m (1180 ft) farther and shifted from a center channel location upstream to the one-third channel location on the Iowa side, encroaching on the navigation channel area.

The channels on either side of the island and shoal region were at least 3.7 m (12 ft) deep and reached depths of 6.1 m (20 ft) on the Illinois side. At one time in the past, the navigation channel was located on the Illinois side of the island. Almost immediately downstream of the shoal region, a depression 120-150 m (390-490 ft) wide and about 700 m (2300 ft) long in the center of the channel reached depths of 8.5 m (28 ft). The portion of this depression that was farthest upstream provided the location for disposal of the dredged sand. At the time of disposal, the bottom material in this depression was primarily fine sand.

Water depths downstream of the disposal site were generally greater than 4.3 m (14 ft) across the entire channel, decreasing abruptly at the banks and near islands on the Illinois side. The region of primary concern with regard to the modification of habitats due to transport of sand from the disposal area was Stone Slough. The two principal entrances to Stone Slough occur about 1 km (0.6 mi) downstream from the disposal area. They have narrow, but deep, channels into the slough and connect with a channel through the slough that parallels the main channel. At the upstream end, the channel in the slough is only about 3-6 m (10-20 ft) wide and is surrounded by shallows generally less than 1 m (3 ft) deep. The channel widens in the downstream direction. The bottom in the shallows is mud, while the bottom of the deep channel is sand. The presence of the sand bottom and general observations by District personnel suggest that the flow through Stone Slough is significant during high water conditions. Thus, the possibility of transport of sand from the disposal area into Stone Slough after disposal had to be addressed in the experiment.

1.4.2 Whitney Island Site

The Whitney Island experimental site is in Pool 22 about 19 km (12 mi) upstream from Lock and Dam 22 and about 6 km (4 mi) upstream from Hannibal, Missouri. The site is about 2 km (1.2 mi) downstream from Whitney Island. As indicated in Fig. 3, the area

*In Sec. 1.4, all depths are relative to flat-pool elevation.

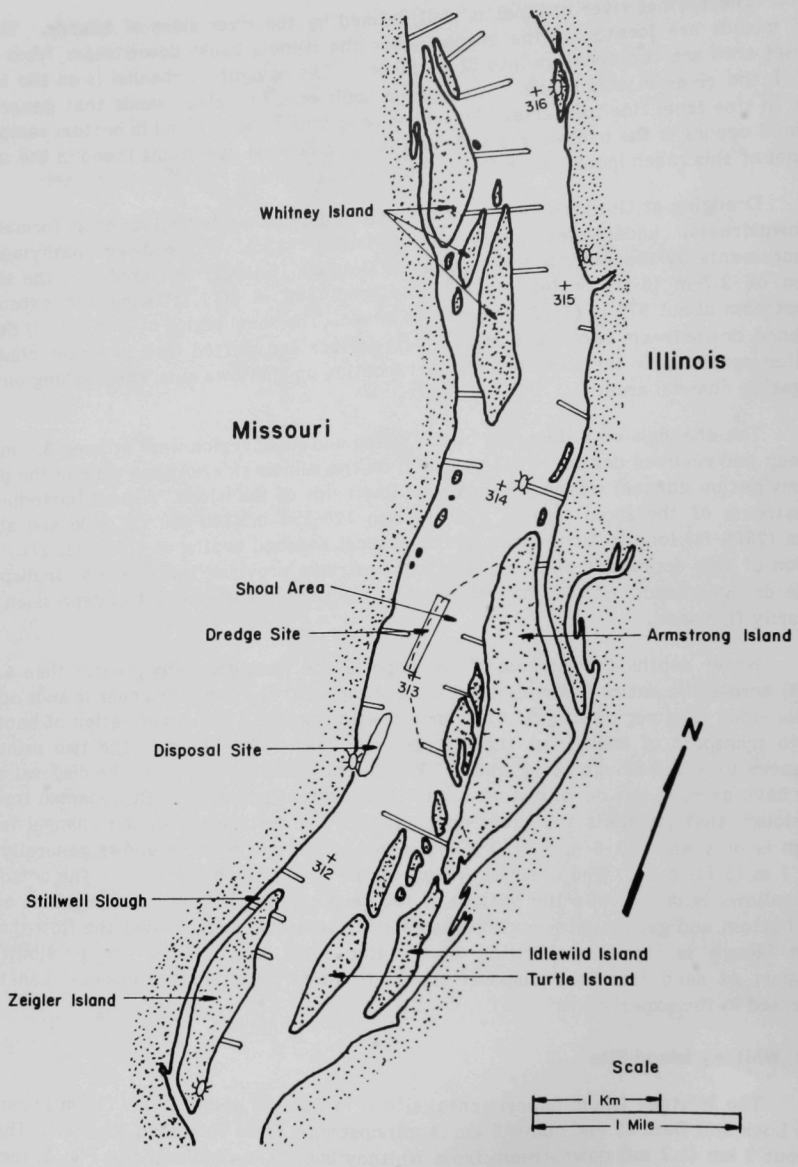

FIGURE 3 Whitney Island Experimental Site in Pool 22 of the Upper Mississippi River

dredged in September 1982 extended from about river mile 313.0 to mile 313.4, and the disposal area extended from about mile 312.3 to mile 312.8.

In contrast to the Gordon's Ferry site, the reach for the Whitney Island experiment is not straight and has more complex geometry. The navigation channel or sailing line follows the outside (Illinois side) of the bend around Whitney Island, crosses the river off Armstrong Island, hugs the bank on the Missouri side, and passes between Zeigler Island and Turtle Island before bending toward the city of Hannibal. The river channel width varies from 400 m (1300 ft) to 730 m (2400 ft) in the reach, and submerged wing dams protrude from the banks on both the Missouri and Illinois sides. In the portion of the reach involved in the experiment (dredging and disposal areas), the deep water is predominately along the Missouri shore, and depths decrease gradually from the nine-foot navigation depth within about 150 m (490 ft) of the Illinois bank. Revetment protects the Missouri bank near the disposal site. The bottom sediments are clean sands that generally range from medium to coarse, although some fine sands are present. Large sand dunes are often found along the bottom in the vicinity of the disposal area.

Shoaling from the Illinois bank outward just above river mile 313 was detected in an August 18, 1982, bathymetric survey by the Corps. This region of channel crossing between wing dams had shoaled such that the opening between the bar on the Illinois shore and the wing dam from the Missouri shore was reduced to about 120 m (390 ft). The bar continued down the Illinois side of the river along Armstrong Island and offshore about the length of the wing dams. Only that portion of the bar constricting the opening between wing dams was dredged. Downstream of river mile 313 on the Missouri side of the river, a hole 6.1 m (20 ft) or more deep and about 200 m (650 ft) wide extended for about 0.8 km (0.5 mi). This depression next to the bank and along the edge of the navigation channel was chosen for the disposal area.

About 0.8 km (0.5 mi) downstream from the disposal area, Stillwell Slough, behind Zeigler Island, has its upstream entrance. Although a submerged wing dam is positioned across the entrance and the navigation channel bends away from the slough, it was obvious that the backwater area might be impacted by the disposal activity.

1.5 SCOPE OF THIS REPORT

The experimental procedures and methods are detailed in Sec. 2. The field experiment at Gordon's Ferry is described in Sec. 3, including the dredging and disposal operations and the results of seven postdisposal surveys occurring over a period of 588 days after disposal. Similarly, Sec. 4 covers the experiment at the Whitney Island site, including results from five postdisposal surveys conducted within 249 days after disposal. Section 5 summarizes the results from the two field experiments and discusses the conclusions to be drawn regarding movement of material following thalweg disposal.

2 EXPERIMENTAL PROCEDURES

2.1 DREDGING AND TAGGING OPERATION

Prior to the dredging operation at each site, dyed sand was prepared by the Rock Island District. The dye used was Day-Glo Rocket Red (AX13)™ obtained from the Day-Glo Corporation of Cleveland, Ohio. This dye fluoresces at approximately 620 nm in the visible spectrum when excited by near-ultraviolet light (350-450 nm). The sand was chosen to match approximately the natural sand at the dredging site in terms of grain size classification. Enough dyed sand was prepared to produce a concentration by weight of about 100-1000 parts per million (ppm) when mixed with the estimated quantity of dredged material to be tagged at the site. This proportion corresponded to about 9000 kg (10 tons) of dyed sand.

The dyed sand was prepared by combining in a concrete mixer the dye, a vinyl plastic adhesive, dry sand, and enough acetone to dissolve the dye and plastic. The acetone evaporates readily during mixing so that the sand particles are individually coated and do not clump together. The dyed sand was then packaged in 34-39-kg (75-85-lb) bags for convenient handling.

The dredging at each site was accomplished by the *William A. Thompson*, which is shown in Fig. 4. The *Thompson* is a hydraulic cutter-head dredge with a nominal maximum capacity of 19,000 m^3 (25,000 yd^3) of material per day. Assuming a typical mass to volume ratio for sand of 1600 kg/m^3 (100 lb/ft^3), this capacity corresponds to 31 $\times$ 10^6 kg/day (34,000 tons/day). The dredged material is carried as a slurry from the cutter head, through the main pump, to a 0.5-m- (20-in.-) diameter discharge pipeline. The dredge proceeds along the cut in an upstream direction, and the floating discharge pipeline transports the dredged material to the downstream disposal site.

When the dredge and discharge areas are separated by a fairly large distance, as at the Whitney Island site, a booster pump is needed in the discharge pipeline. The end of the discharge pipe is above the water surface and is equipped with an attachment that spreads the effluent into a fan shape about 20 m (65 ft) wide (see Fig. 5).

The dyed sand was injected into the pipeline using a simple mechanism built by personnel aboard the *Thompson*. The injection system is shown schematically in Fig. 6. It consists of an open mixing tank (55-gal drum) with inflow and outflow water lines. Water from the dredge's auxiliary water system enters the mixing tank near the bottom at high velocity to produce a turbulent mixing effect. Dyed sand is poured into the tank by hand in a nearly continuous manner, and the water/dyed-sand mixture is withdrawn through the outflow line, which leads to the suction side of the main pump.

Hand-operated valves in the inflow and outflow lines are used to balance the water flow rates so as to maintain a water level in the tank that ensures thorough mixing of the dyed sand and water and prevents buildup of sand in the bottom of the tank. The rate at which dyed sand was added to the mixing tank was based on the amount of dyed sand available and the estimated duration of the tagging operation. The injection rate was typically 7 kg/min (16 lb/min) at the Gordon's Ferry site and 2 kg/min (4 lb/min) at the Whitney Island site.

FIGURE 4 Hydraulic Cutter-Head Dredge *William A. Thompson* Used to Maintain the Nine-Foot Navigation Channel on the Upper Mississippi River

FIGURE 5 Downstream End of Floating Discharge Pipeline with Surface Spreader Attachment

2.2 SURVEY PROCEDURES

Argonne conducted surveys of the disposal area and downstream areas to determine the location of the tagged disposal material and changes in river bottom bathymetry. A 7.6-m (25-ft) Monark aluminum work boat was used for these surveys. The boat has a fully enclosed, heated cabin to protect equipment during cold or rainy weather.

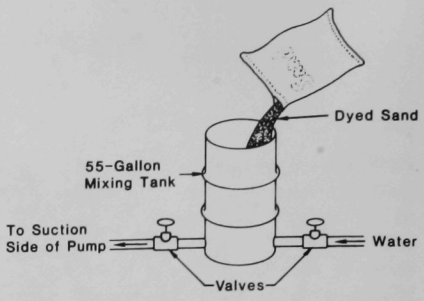

FIGURE 6 Injection System Used to Tag Dredged Material with Dyed Sand

2.2.1 Boat Positioning System

Accurate positioning of the work boat during these surveys is required for interpretation of dyed sand observations and bathymetric measurements. A real-time boat-position plotting system, which includes a Motorola Mini-Ranger™, a Hewlett-Packard programmable calculator (HP 9810A), and an x-y flatbed plotter, was used to navigate the boat and determine its position. The positioning system uses two fixed shore-based transponders, which provide the range information used to calculate boat position by trilateration. The boat position is then displayed on the x-y plotter, which can be viewed by the boat pilot. The accuracy of the system depends somewhat on the relative geometry of the shore stations and the boat. However, for typical configurations, the position of the boat can be determined to within a few meters.

A convenient rectangular coordinate system was established at each experimental site for use with the positioning system. The x axis was chosen to be in an east-west orientation, with the increasing direction of x being eastward. The y axis was chosen to lie in a north-south orientation, with the increasing direction of y being northward. The origin was selected so that all x and y coordinates in the study area would be positive. Sites for the shore-based transponders were established based on shore survey sites supplied by the Rock Island District. River charts, also supplied by the District, were used to establish the location of the banks of the main channel of the river in terms of the x-y coordinate system. An electronic digitizer was used to extract this information from the charts and put it in a form suitable for computer storage and manipulation. This information was used to prepare plotter charts for the onboard x-y plotter that included local shorelines and other features.

2.2.2 Bathymetric Measurements

Bathymetry was measured in the vicinity of the disposal area using the positioning system described in Sec. 2.2.1 and a Raytheon Model DE719B recording depth sounder. Once the disposal area was identified, a series of equally spaced, parallel, straight-line transects was established on the plotter chart of the positioning system. The survey boat was driven at a constant speed along these transects, while the water depth was recorded as a continuous trace on the strip chart of the depth sounder. Start

and stop marks were placed on the strip-chart record to correlate with the endpoints of the transects on the plotter chart.

Initially, 10-20 transects in the vicinity of the disposal area were established at each site, and these transects were repeated during subsequent surveys. Because of the difficulty of maintaining a specific boat course in the presence of river currents and winds, the actual boat path did not always precisely follow the established straight-line transect. The boat typically stayed within 5-10 m (15-30 ft) of the established line, but deviations of as much as 20 m (65 ft) did occasionally occur.

2.2.3 Bottom Sampling

During each survey, bottom samples were gathered in and downstream of the disposal area and analyzed to determine the presence of tagged dredged sand. A grid of sampling locations was established on the plotter chart of the positioning system prior to each sampling survey. In general, the sampling locations were more closely spaced in the immediate vicinity of the disposal site in order to resolve the configuration of the disposal pile and reveal any changes that may have occurred since the previous survey. The sampling locations were more widely spaced downstream to include border areas and sloughs as well as the main channel. This spacing permitted investigating the general areas into which the tagged dredged sand may have migrated. Based on initial observations during a survey, sampling locations were added to and deleted from the grid as the survey progressed. Such adjustments increased the resolution in regions of interest and allowed coverage of additional areas into which tagged material may have migrated.

The boat was driven to the sampling location using the positioning system, and the water depth was noted and recorded. A discrete sample of the surficial bottom sediments was then obtained with a Ponar Grab Sampler™. The sampler was attached to a rope and retrieved with the aid of an electric winch on a davit off the side of the survey boat. The sample was then spread onto a 23 cm × 23 cm (9.1 in. × 9.1 in.) tray to form a 0.3-cm (0.12-in.) thick layer (see Fig. 7). At this time, a visual estimate was made of the classification of the bottom material by grain size. The approximate classifications used were mud, silt, fine sand, medium sand, coarse sand, gravel, and rocks.

The sample tray was inserted into a light box, where the surface layer of the sample was illuminated by ultraviolet light from four 6-W black-light fluorescent lamps (see Fig. 8). A preliminary estimate of the number of dyed sand grains on the surface of the sample tray was made by visual inspection. In addition, several photographs at a series of exposure times were taken for later analysis in the laboratory. Kodak Ektachrome™ ASA 200 daylight color slide film (35 mm) was used and Kodagraph Sheeting™ (Kodak No. 152-2978) was used as a filter to suppress the visible blue light produced by the lamps but not the red light from the dyed sand. Finally, the sample was placed in a labeled polyethylene container and saved in case additional analysis might be required.

2.2.4 Selection of Camera Exposure Times

Based on preliminary tests in the laboratory with artificially prepared sand samples containing dyed sand, exposure times of 0.5 s and 2 s with the lens aperture wide open (f/2) were selected for use in the first few field surveys. Once actual field samples were available, it was evident that longer exposure times were necessary to distinguish very small dyed sand grains. However, at longer exposure times, larger sand grains became overexposed and appeared yellow rather than red.

To determine a more appropriate set of exposure times, an actual wet field sample was photographed in the laboratory at a series of many different exposure times. The number of dyed sand grains visible in the resulting slides was then determined as a function of exposure time (see Fig. 9). Initially, the number of visible dyed sand grains increases rather dramatically with exposure time until an exposure time of about 8 s. The number of visible grains then increases fairly slowly until an exposure time of about 16 s is reached. Beyond this point it becomes difficult to distinguish dyed sand grains from shell fragments, which also fluoresce. In addition, because of overexposure, even the background material begins to appear red. Based on these results, exposure times of 2 s, 7 s, and 12 s were used for all field surveys, except the first three surveys at Gordon's Ferry. The shorter exposure times are needed so that the larger dyed sand grains are visible without being overexposed, and the longer exposure times ensure that small grains will be visible yet distinguishable from background material.

FIGURE 7 Surficial Bottom Sample Being Spread onto the Sample Tray

FIGURE 8 Sample Tray Being Inserted into Ultraviolet Light Box for Visual Inspection and Photographing

2.3 DATA REDUCTION

The positioning-system plotter charts, depth-sounder strip charts, exposed photographic film, bottom samples, and other data records were returned to the

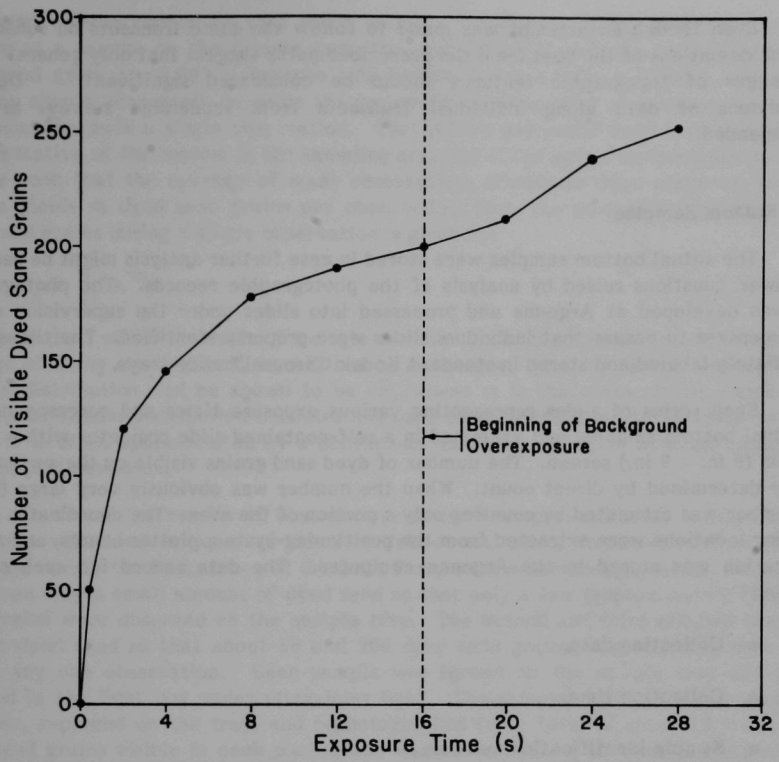

FIGURE 9 Number of Dyed Sand Grains Visible in Photographs of a Single Field Sample as a Function of Exposure Time

laboratory for processing after each field survey. Data were extracted from these records and stored in a format convenient for tabular and graphic presentation by the Argonne computer.

2.3.1 Bathymetric Data

Water depth information was extracted from the depth-sounder strip charts using an electronic digitizer. Each continuous strip-chart record was approximated by a series of several hundred individual points, a number sufficient to resolve topographic structures with length scales on the order of a few meters. Bottom profiles were constructed and stored in the computer by using the endpoints of the transects from the positioning-system plotter charts and local water surface elevation changes from survey to survey as reported by the Rock Island District. Computer programs were developed to present these bottom profiles in various graphical formats.

Even though an attempt was made to follow the same transects on subsequent surveys, deviations of the boat from the prescribed paths suggest that only general trends in changes of topographic features should be considered significant. Detailed comparisons of data along individual transects from successive surveys are not recommended.

2.3.2 Bottom Samples

The actual bottom samples were stored in case further analysis might be required to answer questions raised by analysis of the photographic records. The photographic film was developed at Argonne and processed into slides under the supervision of the experimenters to ensure that individual slides were properly identified. The slides were immediately labeled and stored in standard Kodak Carousel™ slide trays.

Each series of slides representing various exposure times and corresponding to individual bottom samples was examined in a self-contained slide projector with a 23 cm × 23 cm (9 in. × 9 in.) screen. The number of dyed sand grains visible on the surface was usually determined by direct count. When the number was obviously very large (>200), the number was estimated by counting only a portion of the area. The coordinates of the sampling locations were extracted from the positioning-system plotter charts, and all the information was stored in the Argonne computer. The data record for each sample includes:

- Collection date,
- Collection time,
- Sample identification number,
- Sampling location (x-y coordinates),
- Approximate water depth at sampling location,
- Number of visible dyed sand grains on the sample tray,
- Classification of the sample by approximate grain size, and
- Identification number of photographic slides.

Computer programs were developed to present several of these parameters in various graphical formats.

2.3.3 Statistical Significance of Dyed Sand Observations

The average concentration of dyed sand introduced into the dredged material was on the order of 100-1000 ppm. Any sample collected in the field should therefore have

dyed sand concentrations on that order or less. Therefore, in any observation of the surface of a sample on the sample tray, the probability of any one sand grain being a dyed sand grain is ≤0.001. Because this probability is small, a Poisson distribution function should adequately describe the probability of observing a particular number of dyed sand grains in a single observation. That is, if a particular bottom sample is truly representative of the bottom in the sampling area and if the actual concentration of dyed sand is such that the average of many observations of sample trays prepared from the sample yields m dyed sand grains per observation, then the probability of observing n dyed sand grains during a single observation is given by:

$$P_n = \frac{m^n}{n!} e^{-m}$$

It is clear that, while the result of a single observation, n, must be a discrete integer, the average of many observations, m, will not be an integer. The standard deviation, σ, of a Poisson distribution can be shown to be $\sqrt{m}$, where m is the mean of the distribution. Because a Poisson distribution becomes awkward to manipulate when the mean becomes large, it is often approximated by a continuous normal distribution with the same mean and standard deviation.

To see if the results of observations of sand samples collected in the field are consistent with what is expected based on Poisson statistics, three actual field samples collected during the first survey at Gordon's Ferry were selected and tested. One sample contained only a small amount of dyed sand so that only a few (approximately five) dyed sand grains were observed on the sample tray. The second and third samples contained enough dyed sand so that about 50 and 200 dyed sand grains, respectively, were noted during any one observation. Each sample was spread on the sample tray and photographed in the light box under ultraviolet light. The samples were then removed from the tray, replaced on the tray, and rephotographed for a total of about 10 times. The dyed sand grains visible in each photograph were counted, and the results are presented in Table 1. The sample mean, sample standard deviation, and sample range were calculated for each sample and are included in the table. The sample standard deviation is defined by:

$$\sigma_{sample} = \left[\frac{1}{k-1} \sum_{i=1}^{k} (n_i - m)^2 \right]^{1/2}$$

where n_i is the result of an individual observation and k is the total number of observations. The sample standard deviation is often used as an estimate of the standard deviation of the true probability distribution.

In the case of Sample 1, with a mean of 3.4, the Poisson distribution predicts a standard deviation of 1.8, which is very close to the sample standard deviation of 1.7. In addition, the Poisson distribution predicts that for a sample with a true mean of 3.4, 90% of the observations of the sample should yield between one and six dyed sand grains, which is again in excellent agreement with the observed range.

Examining the results of the observations of Sample 2 and Sample 3 shows that the extremes in the range of observed number of dyed sand grains occurred in the first

TABLE 1 Repeated Observations of Three Field Samples Containing Dyed Sand

	Number of Visible Dyed Sand Grains		
Observation	Sample 1	Sample 2	Sample 3
1	2	33	220
2	5	67	253
3	3	42	179
4	4	47	188
5	3	40	228
6	2	40	187
7	1	56	185
8	6	54	185
9	5	52	209
10	-	44	192
Mean	3.4	47.5	202.6
Standard deviation	1.7	9.9	24.2
Range	1-6	33-67	179-253

two to three observations. This result seems to indicate that the surface layer of sand on the sample tray was not representative of the entire sample and that the mixing associated with removing and replacing the samples on the sample tray may have resulted in a more representative surface layer. In the case of Sample 2, if the first two observations are omitted, the sample mean becomes 46.9, the sample standard deviation becomes 6.4, and the sample range becomes 40-56. A Poisson distribution with a mean of 46.9 would predict a standard deviation of 6.8, which is in close agreement with the sample standard deviation. In addition, a normal distribution would predict that 90% of the observations should be in the range 35.6-58.2, which again is in agreement with the observed range. In the case of Sample 3, if the first three observations are omitted, the sample mean becomes 196.3, the sample standard deviation becomes 16.3, and the sample range becomes 185-228. Again, these values are in reasonable agreement with the standard deviation of 14.0 and the range of 173.3-219.3 predicted by the Poisson and normal distribution functions.

From the results of the three tests involving actual field samples, it is concluded that (1) a Poisson probability distribution function can be used to describe the observation process for representative samples; (2) the sample preparation process does not necessarily always produce a representative sample in a statistical sense; and (3) although the sampling process does not always produce a statistically representative sample, the sample will probably be in general agreement (within one to three standard

deviations) with representative samples. Given the characteristics of the Poisson distribution and the laboratory results for Sample 1 (see Table 1), it is evident that observations of samples with small amounts of dyed sand can exhibit a wide range of results. That is, the standard deviation of the distribution is of the same order of magnitude as the mean. In fact, for samples with very low concentrations of dyed sand, a significant probability exists that no dyed sand will be observed on the surface of the sample tray. The probability that at least one dyed sand grain will be observed when the mean number of dyed sand grains observed is m is given by:

$$P_{n>0} = 1 - P_0$$

$$= 1 - e^{-m}$$

For there to be a fairly high (≥95%) probability that dyed sand will be detected in a single observation, the dyed sand concentration must be such that the mean number of observed dyed grains is at least 3.0. Only when dyed sand concentrations are greater than that required to yield an average of three or more dyed sand grains per sample tray is there a reasonable certainty that the tagged dredged material will be identified by the sampling procedure. When dyed sand concentrations are less than this minimum, the presence of individual dyed sand grains indicates that some tagged material has moved into the sampling area, but little if any statistical significance can be attached to individual results.

3 FIELD EXPERIMENTS AND RESULTS AT GORDON'S FERRY

Section 3 describes the field measurements and presents the data from the experiment at Gordon's Ferry. Section 3.1 describes the tagging and disposal operations, and Sec. 3.2 discusses the first survey (Survey I) and describes the conditions of the disposal pile immediately following the dredging operation. The subsequent surveys (Surveys II-VII) are discussed in Sec. 3.3, while Sec. 3.4 briefly summarizes the experimental results. The important experimental activities conducted at Gordon's Ferry are listed in Table 2, along with the dates, the times after disposal, and the number of bottom samples collected during each activity. Figure 10 is a plot of mean daily river

TABLE 2 Experimental Activities at the Gordon's Ferry Disposal Site

Experimental Activity	Date	Time after Disposal (days)[a]	Number of Bottom Samples Collected
Background bottom samples	October 26, 1981	-2	13
Predisposal bathymetry	October 26, 1981	-2	NA[b]
Dredging and disposal operations	October 27-28, 1981	0	NA
Survey I	October 28-30, 1981	0	86
Survey II	November 5-6, 1981	8	64
Survey III	December 2-3, 1981	35	56
Survey IV	March 30-April 1, 1982	153	49
Survey V	June 2-3, 1982	217	79
Survey VI	October 12-13, 1982	349	77
Survey VII	June 7-9, 1983	588	151

[a]Time from the end of disposal operations on October 28, 1981.

[b]Not applicable.

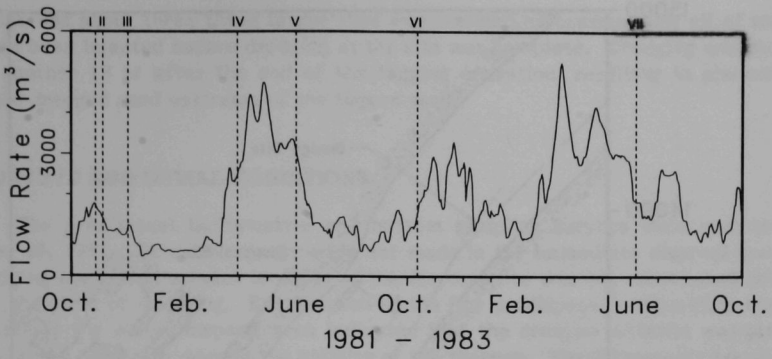

FIGURE 10 Mean Daily River Discharge for the Gordon's Ferry Site as Recorded at Lock and Dam 12, with the Dates of the Surveys Indicated

discharge recorded by the Rock Island District at Lock and Dam 12 (about 12 km* downstream of the disposal area), with the dates of the Argonne field surveys indicated.

3.1 DREDGING, TAGGING, AND DISPOSAL OPERATION

The *Thompson* commenced dredging at 0120 hr on October 27, 1981, at the downstream end of the area indicated in Fig. 11. The discharge pipeline extended downstream from the stern of the *Thompson* a distance of about 750 m. As the dredge progressed upstream, the connected pipeline followed at the same rate. The tagged sand was deposited along a relatively straight, 300-m long depression in the river bottom that was about 8.0-8.5 m deep. The end of the discharge pipe was equipped with an attachment that spread the effluent into a fan shape (see Fig. 5) about 15-20 m wide. Dyed sand was injected into the dredge line as described in Sec. 2.1.

The sand that was dyed for the tagging operation was dredged from the Upper Mississippi River near river mile 610. The sand was dyed by Rock Island District personnel in the manner described in Sec. 2.1. Sieve analysis of the sand, prior to dyeing, indicated that both the median grain size, d_{50}, and the geometric mean grain size, d_g, were about 0.40 mm; and the geometric standard deviation, σ_g, was about 1.4. In general, the sand would be classified as mostly fine.

Injection of dyed sand was begun at the start of dredging at 0120 hr on October 27, 1981. Dyed sand injection continued during the dredging operation until 0712 hr on October 28, 1981. The dredge was not operating during 4.3 hr of that period, so that the total time for dyed sand injection was 25.6 hr. During those hours about 11,400 kg of dyed sand was injected, for an average rate of 445 kg/hr.

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*In Sec. 3 and the following sections of this report, conversions to English units will not be provided.

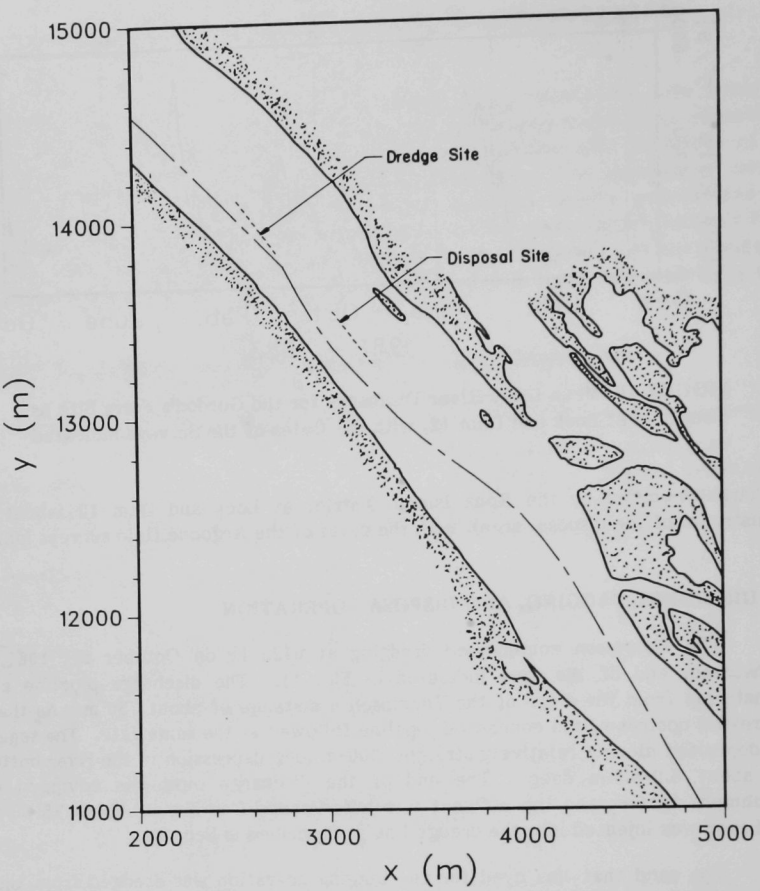

FIGURE 11 Map of the Gordon's Ferry Site Showing Dredging and Disposal Areas

The average concentration of dyed sand by weight can be estimated to be 350 ppm given the nominal (maximum) dredging capacity of the *Thompson* (19,000 m^3/day), the total amount of dyed sand injected (about 11,400 kg), and the total time of dyed sand injection (25.6 hr). However, Corps of Engineers personnel onboard the *Thompson* estimated that the actual cutting rate at Gordon's Ferry was only about one-third of the maximum capacity of the dredge, resulting in an average concentration of dyed sand of about 1000 ppm.

The injection rate for dyed sand had been adjusted during dredging operations to yield a concentration of about 350 ppm, but the rate was based on an anticipated cutting

rate that was about three times larger than was realized. Consequently, all of the dyed sand had been injected before dredging at the site was complete. Dredging continued for about another 18 hr after the end of the tagging operation, resulting in placement of untagged dredged sand upstream of the tagged sand.

3.2 SURVEY I AND INITIAL CONDITIONS

The predisposal bathymetric and bottom sampling surveys were conducted on October 26, 1981. Detailed surveys were not made in the immediate disposal area prior to dredging because the exact location of the disposal site was not established until just before the start of dredging. Examination of the few predisposal bathymetric transects that were in the actual disposal area indicated that the dredged material was placed in an area about 8.0-8.5 m deep in the vicinity of the thalweg. These transects are shown in Sec. A.1 of App. A.

Two of the 13 predisposal bottom samples were in the immediate area of the disposal pile. One sample contained fine sand and the other contained a mixture of fine sand and mud. Three other bottom samples that were near the disposal area all contained fine sand, with one sample being exclusively fine sand, one a mixture of fine sand and mud, and one a mixture of fine and medium sand and mud. Figure 12 is a plot of the location and type of bottom sediment for these five samples. The key for the sediment classifications used in Fig. 12 and all similar figures in this report is: Y - mud, S - silt, F - fine sand, M - medium sand, C - coarse sand, G - gravel, and R - rock.

One objective of collecting predisposal bottom samples was to determine if there was any naturally occurring bottom material that fluoresced at about the same wavelength as the dyed sand. Two of the photographs of the predisposal bottom samples revealed dyed sand particles. These particles were attributed to contamination that occurred during a sampling and detection system demonstration near Princeton, Iowa, in August 1981. While dyed sand was being dispersed from the stern during the demonstration, wind blew fine dyed sand particles into the cabin of the survey boat, thereby contaminating the detection equipment. Although the boat and equipment were vacuumed and washed after the demonstration, all of the contaminating dyed sand was apparently not removed. In fact, on one occasion when a background sample was being visually inspected, a dyed sand particle fell onto the sample tray from the top of the light box.

Immediately after the dyed sand injection was completed, a detailed bathymetric survey was carried out. Eleven east-west transects about 300-500 m long and 50 m apart were established in and immediately downstream from the disposal area. Individual bathymetric transect plots are available in Sec. A.1 of App. A. Figure 13 shows the results from all 11 transects in the form of a perspective plot, with the base of the plot taken arbitrarily at a depth of 10 m. The direction of flow of the river is from the upper left-hand corner to the lower right-hand corner of the plot. The pile formed by the disposal operation is evident in the second through sixth transects (y = 13,500 m to y = 13,300 m) between about x = 3050 m and x = 3250 m in the east-west direction. Examination of the sparse predisposal and detailed postdisposal bathymetric data showed that the disposal pile was about 1.2-1.9 m high, about 300 m long, and about 25-45 m wide at

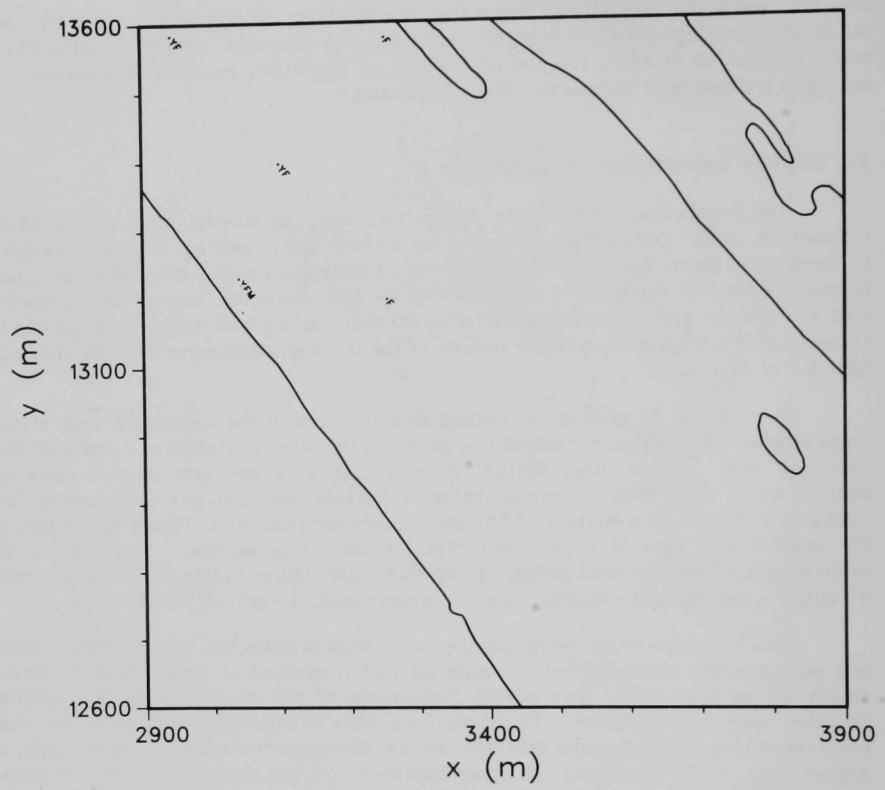

FIGURE 12 Approximate Classification of Bottom Sediments at Sampling Locations during the Predisposal Survey at the Gordon's Ferry Disposal Site

the base. It was located in the vicinity of the thalweg of the river, where the natural water depth was about 8.0-8.5 m.

Bottom sampling for Survey I was undertaken on October 28, 1981, the day the dredging was completed, in the manner described in Sec. 2. The initial conditions of the disposal area shortly after dredging are indicated in Fig. 14. Figure 14 shows the bottom sampling locations, the number of dyed sand grains observed on the surface of the 23 cm × 23 cm sample tray at each location, the paths of the bathymetric transects, and the peak and lateral extent of the disposal pile as determined from the bathymetric survey results. Within the resolution of the sampling grid, the location of the disposal pile was confirmed by both the bathymetry and the dyed sand distribution. An area containing samples with high counts of dyed sand extended about 500 m downstream of where the physical pile appeared on the bathymetric transects. This downstream extension of dyed

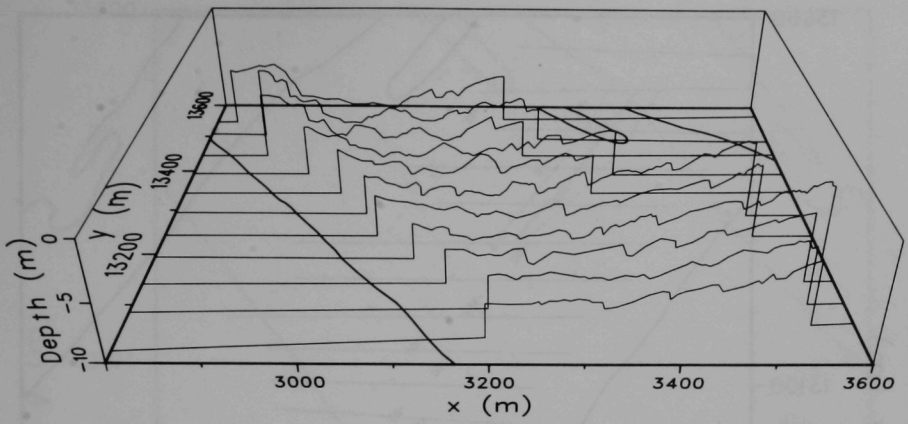

FIGURE 13 Perspective Plot of Bathymetric Transects for Survey I at the Gordon's Ferry Disposal Site

sand was probably the result of finer particles being carried downstream by the current before reaching the bottom during disposal and some particles sloughing off of the pile after disposal.

The sampling grid for the first survey (and for Surveys II-IV also) was too coarse for detailed definition of the immediate disposal area. The initial sampling grid was spread over a large portion of the river reach beyond the immediate disposal area because of concern that the tagged material might disperse rather widely soon after disposal. Evidence to the contrary in the first few surveys resulted in redefinition of the sampling grid in the vicinity of the disposal pile.

Figure 15 shows the location of the sampling stations and the contour chosen to delineate the tagged material. The contour includes all sampling locations where three or more dyed sand grains were found on the surface of the sample tray. It was chosen on the basis of the statistical argument discussed in Sec. 2. The initial area occupied by the tagged material defined by the three-dyed-sand-grain contour is about 800 m long and 50-100 m wide, with an area of 58,000 m^2.

Bottom sampling was continued downstream until a transect was completed where, for all stations, no dyed sand was noted by onboard visual inspection of the bottom sample. Plots of the entire sampling grid with all the locations where dyed sand was found indicated are included in Sec. A.2 of App. A. The transect on which dyed sand was last found on Survey I was about 200 m beyond the downstream extent of the original tagged sand area as denoted by the three-dyed-sand-grain contour. Samples containing one or two grains were found at three stations on this transect. No dyed sand was found in samples from Stone Slough on Survey I.

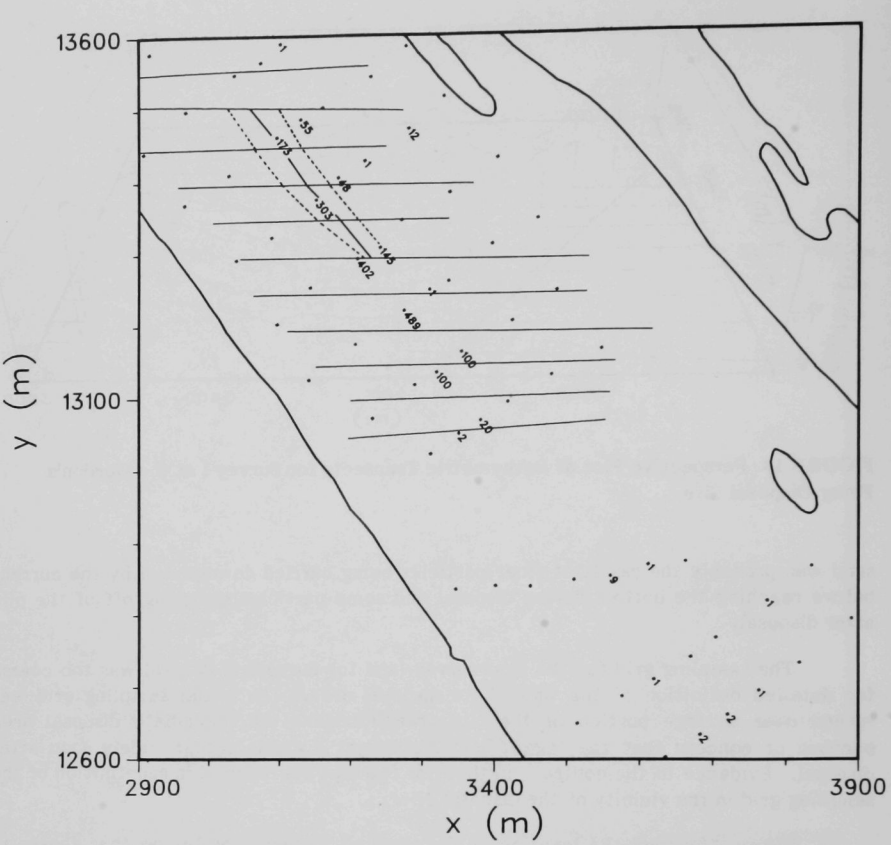

FIGURE 14 Location of Bathymetric Transects and Bottom Sampling Stations for Survey I at the Gordon's Ferry Disposal Site (location of the pile and the number of dyed sand grains observed are noted)

The classification of the bottom sediments at each of the sampling locations of Survey I is indicated in Fig. 16. The bottom material was predominantly fine sand.

In summary, the conditions at the Gordon's Ferry site just after dredging, as determined during Survey I, were:

1. The portion of the tagged dredged sand that could be distinguished bathymetrically from other bed forms (termed the pile) was about 300 m long and 40 m wide.

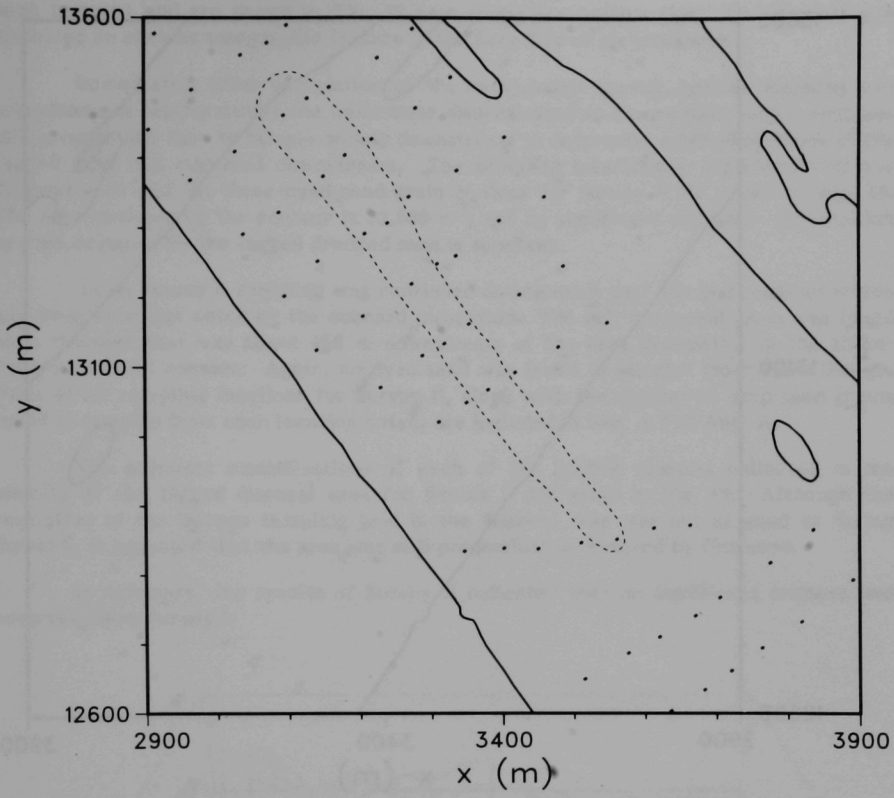

FIGURE 15 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey I at the Gordon's Ferry Disposal Site

2. The tagged dredged sand, as indicated by the three-dyed-sand-grain contour, covered an area of about 58,000 m^2 (800 m long and 75 m wide) that included the pile but extended about 500 m farther downstream.

3. Single grains of dyed sand were found at three stations on a transect about 200 m downstream of the area enclosed by the three-dyed-sand-grain contour.

4. The surficial bottom sediments were predominantly fine sand.

5. No dyed sand was found in samples from Stone Slough.

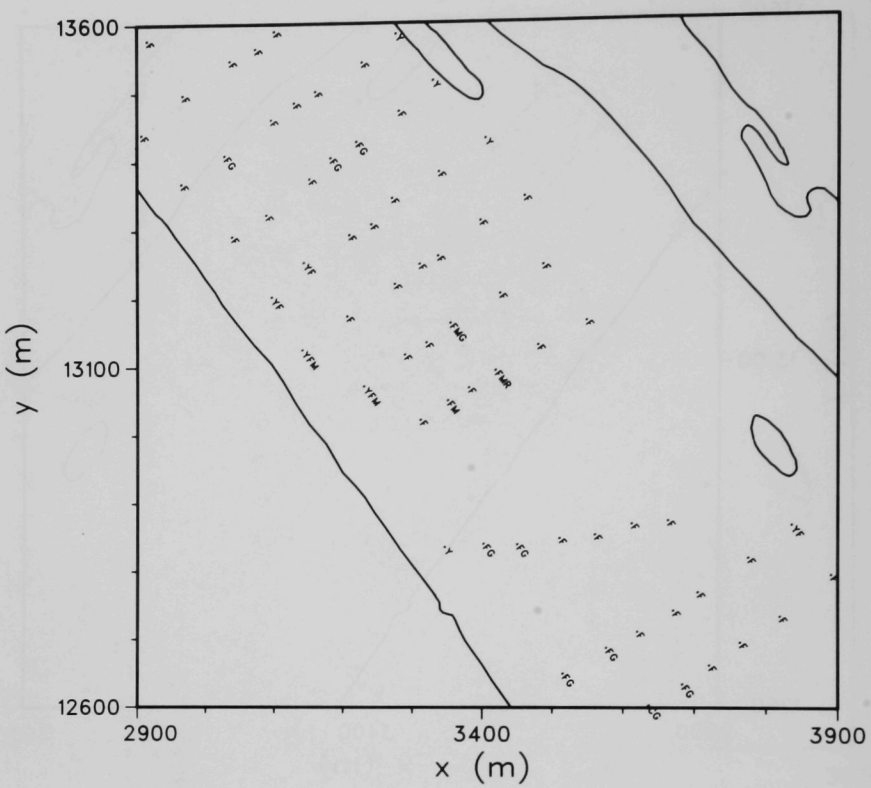

FIGURE 16 Approximate Classification of Bottom Sediments at Sampling Locations for Survey I at the Gordon's Ferry Disposal Site

3.3 RESULTS OF SUBSEQUENT SURVEYS

3.3.1 Survey II

On November 5, 1981, eight days after the first survey, a second bathymetric survey was made, which followed the same 11 east-west transects as closely as possible. Because of the difficulty in maintaining a specific boat course in the presence of river currents and winds, the transects did not always coincide. However, the transects were typically within 5-10 m, with occasional deviations of as much as 20 m. Detailed comparisons between corresponding transects are not appropriate, and only general trends in changes in bottom topography should be considered meaningful. The results of bathymetric measurements from the second survey are shown in Sec. A.1 in App. A for

each transect and are shown in Fig. 17 as a single perspective plot. The disposal pile remained an obvious topographic feature in the first five or six transects.

Immediately after completion of the bathymetric survey, bottom sampling was undertaken to briefly survey the immediate disposal area to ensure that tagged sand was still present and then to sample widely downstream to determine whether portions of the tagged sand had migrated downstream. The sampling locations in the vicinity of the disposal area and the three-dyed-sand-grain contour for Survey II are shown in Fig. 18. The area enclosed by the contour is 53,000 m^2, and no significant change in the location or area occupied by the tagged dredged sand is apparent.

As on Survey I, sampling was continued downstream past the last transect where any dyed sand was noted by the onboard inspection. The last dyed sand grain was found on a transect that was about 450 m downstream of the area delineated by the three-dyed-sand-grain contour. Again, no dyed sand was found in samples from Stone Slough. Plots of all sampling locations for Survey II, along with the number of dyed sand grains found in samples from each location noted, are included in Sec. A.2 of App. A.

The sediment classifications of each of the bottom samples collected in the vicinity of the tagged disposal area for Survey II are given in Fig. 19. Although the resolution of the bottom sampling grid in the disposal area was not as good as during Survey I, it appeared that the area was still predominantly covered by fine sand.

In summary, the results of Survey II indicated that no significant changes had occurred since Survey I.

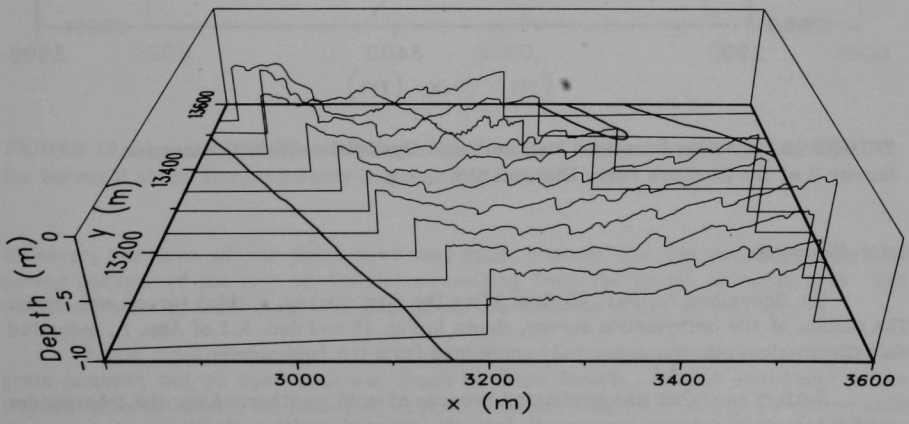

FIGURE 17 Perspective Plot of Bathymetric Transects for Survey II at the Gordon's Ferry Disposal Site

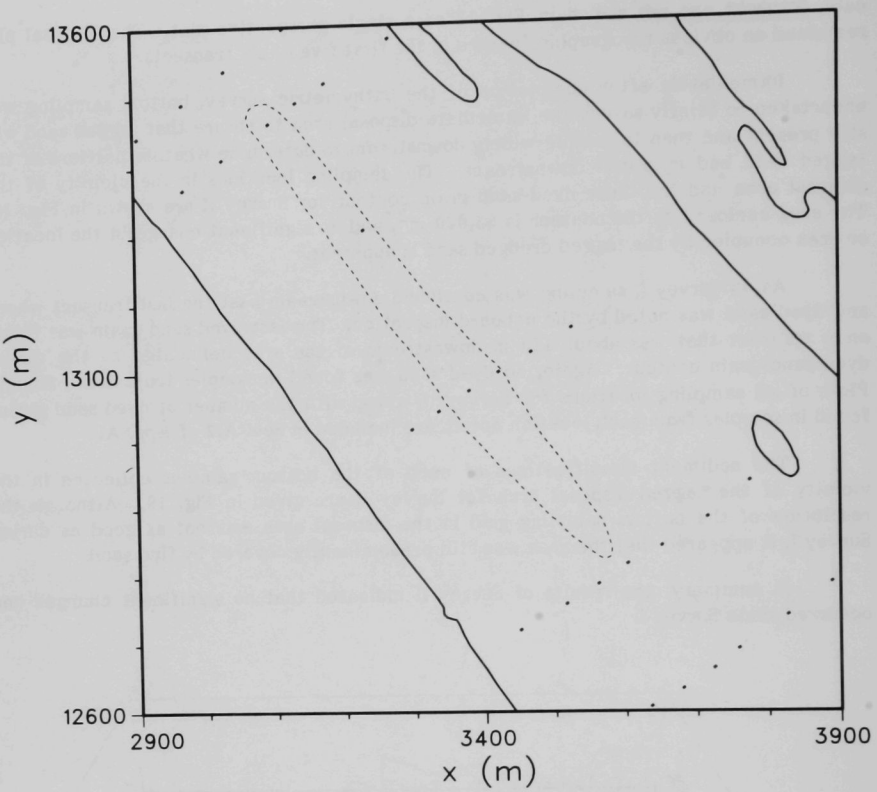

FIGURE 18 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey II at the Gordon's Ferry Disposal Site

3.3.2 Survey III

On December 2, 1981, 35 days after the first survey, a third survey was made. The results of the bathymetric survey, shown in Fig. 20 and Sec. A.1 of App. A, indicated that the physical pile was essentially unchanged from the first survey.

Bottom sampling was minimized because of cold weather. Also, the transponder coordinates were entered incorrectly into the onboard position-plotting system at one point during the survey. As a result, the locations sampled in the vicinity of the disposal area were not the ones intended. In fact, some locations where large amounts of dyed sand were expected were not sampled. These circumstances resulted in a sparse set of bottom samples in the disposal area. Within the resolution of this sampling grid, no change in the position of the three-dyed-sand-grain contour could be seen (see Fig. 21).

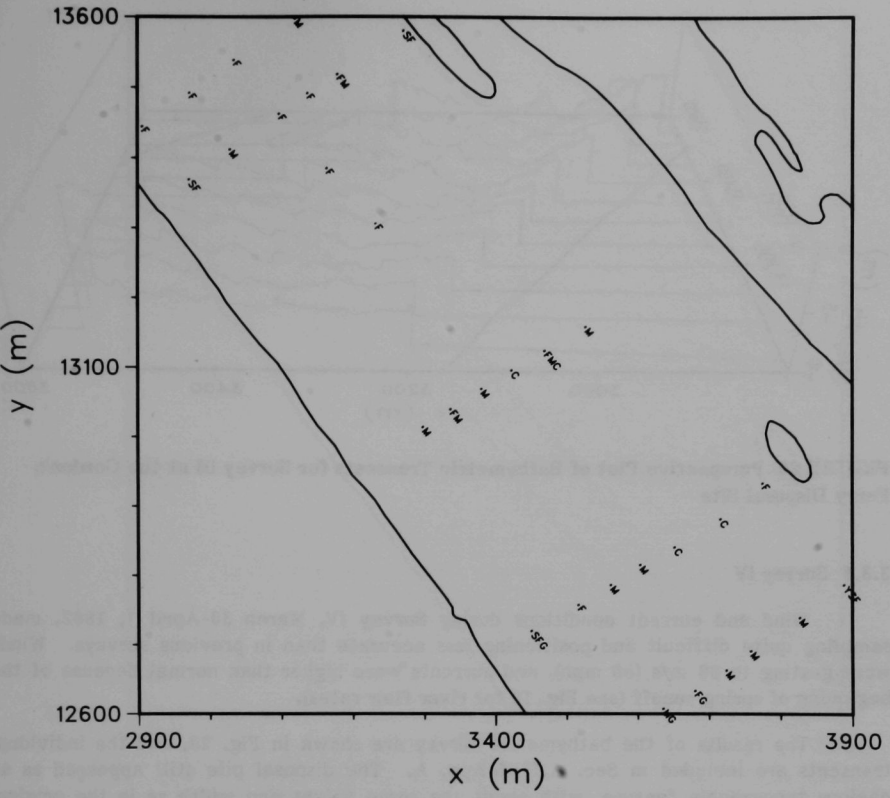

FIGURE 19 Approximate Classification of Bottom Sediments at Sampling Locations for Survey II at the Gordon's Ferry Disposal Site

However, the area of the three-dyed-sand-grain contour was not calculated for this survey because of the lack of definition resulting from the sparse sampling grid. The detailed results of the bottom sampling survey are included in Sec. A.2 of App. A.

Single dyed sand grains were found 900 m downstream of the three-dyed-sand-grain contour, but no dyed sand was found in Stone Slough. Bottom sediments in the disposal area could still be classified as predominantly fine sand with some coarse sand (see Fig. 22).

In summary, the results of Survey III indicated that the bathymetry and the three-dyed-sand-grain contour were very similar to those of the first survey. Single dyed sand grains were found farther downstream than in the previous survey but, again, no dyed sand was found in Stone Slough. The classification of bottom sediments showed no major changes despite the appearance of some coarse sand.

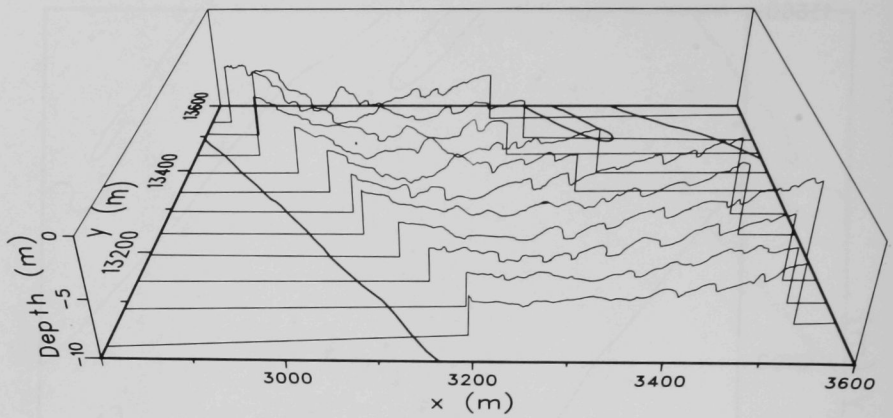

FIGURE 20 Perspective Plot of Bathymetric Transects for Survey III at the Gordon's Ferry Disposal Site

3.3.3 Survey IV

Wind and current conditions during Survey IV, March 30-April 1, 1982, made sampling quite difficult and positioning less accurate than in previous surveys. Winds were gusting to 22 m/s (50 mph), and currents were higher than normal because of the beginning of spring runoff (see Fig. 10 for river flow rates).

The results of the bathymetric survey are shown in Fig. 23, and the individual transects are included in Sec. A.1 of App. A. The disposal pile still appeared as an obvious topographic feature, with about the same height and width as in the original survey.

Bottom sampling in the disposal area was designed to determine whether the tagged sand still remained in the original disposal area. Figure 24 shows the sampling locations in that area, along with the three-dyed-sand-grain contour.* The area enclosed by the three-dyed-sand-grain contour is 51,000 m^2. This survey provided the first evidence that some of the tagged material in the disposal area had moved, although the evidence was not entirely conclusive because of the limited sampling resolution in the immediate vicinity of the disposal area. On the basis of a single sampling location (at about x = 3600 m and y = 12,800 m), the three-dyed-sand-grain contour now extended an additional 50 m downstream. During Survey II the bottom sample collected at that

*As discussed in Sec. 2.2.4, camera exposure times were changed from 0.5 s and 2 s to 2 s, 7 s, and 12 s for Survey IV and all subsequent surveys. Consequently, direct comparison of dyed-sand-grain counts from Surveys I-III with later surveys may be misleading.

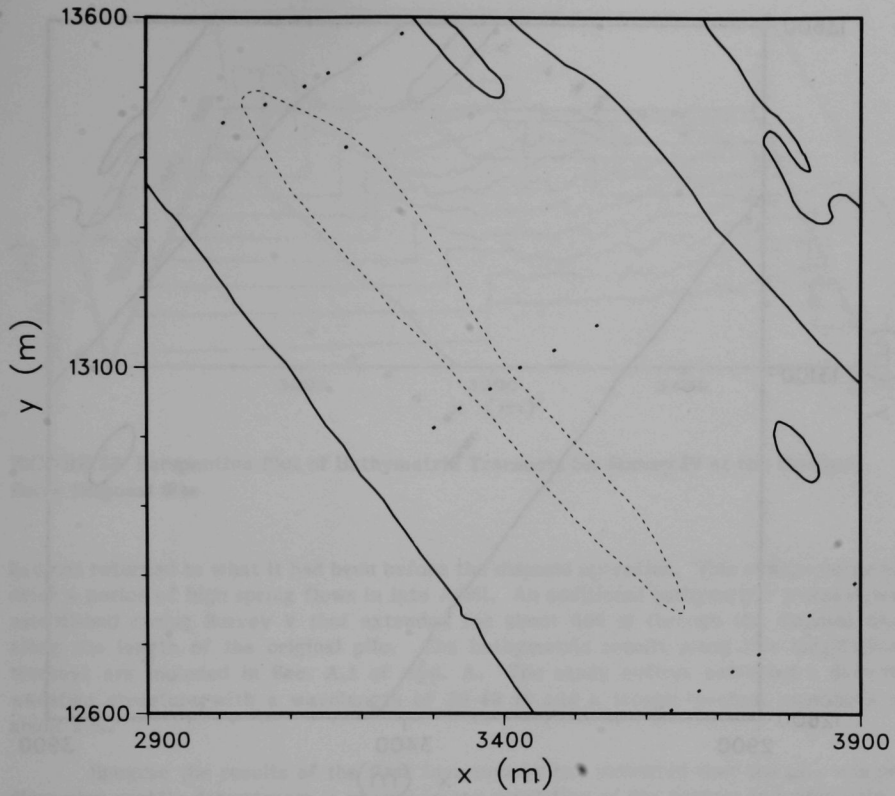

FIGURE 21 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey III at the Gordon's Ferry Disposal Site

location contained one dyed sand grain. No samples were collected there during Survey I or Survey III, but in Survey IV the sample contained six grains. However, during Survey I, a sample collected about 50 m upstream from that location contained nine grains.

As in previous surveys, sampling continued downstream until a transect was completed for which no dyed sand was evident by visual inspection. Dyed sand grains that were too small to be seen by direct visual observation were noted later on the photographs from the last transect, which was 1300 m downstream of the original disposal area. No dyed sand was found in Stone Slough on Survey IV. The complete results of the bottom sampling survey are included in Sec. A.2 of App. A.

The sediment characteristics of samples from Survey IV (see Fig. 25) indicated that some change had occurred since Survey I; many samples contained medium and coarse sand, while few were made up of exclusively fine sand.

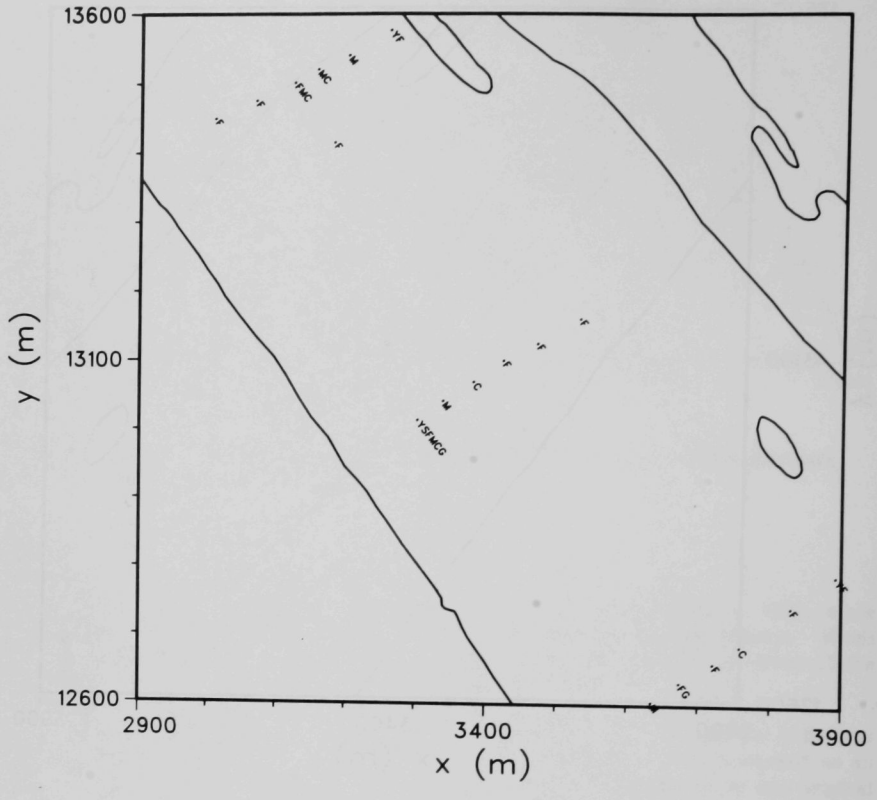

FIGURE 22 Approximate Classification of Bottom Sediments at Sampling Locations for Survey III at the Gordon's Ferry Disposal Site

In summary, results from Survey IV indicated that some changes, although minor, may have occurred. The area of dyed sand appeared to extend slightly farther downstream (about 50 m). The bottom material had become somewhat coarser, but no significant changes were apparent in the bathymetric data in the vicinity of the disposal pile.

3.3.4 Survey V

A major change occurred in the bathymetry in the disposal area between Surveys IV and V (153 to 217 days after dredging). As can be seen from the results of Survey V (June 2-3, 1982) as presented in Fig. 26 and Sec. A.1 of App. A, the disposal pile was no longer distinguishable from other bed forms, although the average bottom elevation

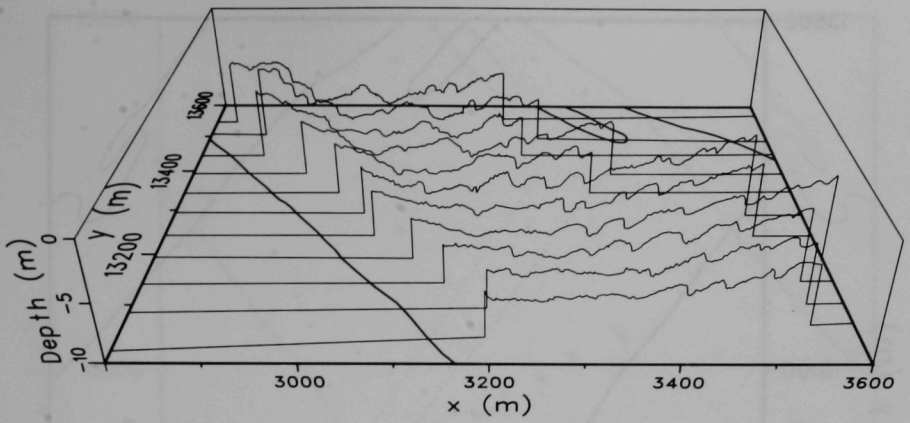

FIGURE 23 Perspective Plot of Bathymetric Transects for Survey IV at the Gordon's Ferry Disposal Site

had not returned to what it had been before the disposal operation. This change occurred after a period of high spring flows in late April. An additional bathymetric transect was established during Survey V that extended for about 690 m through the disposal area along the length of the original pile. The bathymetric results along this longitudinal transect are included in Sec. A.1 of App. A. The sandy bottom exhibited a definite wavelike structure with a wavelength of 30-40 m and a trough-to-crest amplitude of about 2 m.

Because the results of the first four surveys had indicated that the pile was not dispersing rapidly downstream, a change in the resolution of the bottom sampling grid in the disposal area was made during Survey V. Greater resolution in the disposal area was sought to delineate the extent of the major portion of the tagged sand more precisely.

The results of the bottom sampling in the disposal area (see Fig. 27) indicated little change in the three-dyed-sand-grain contour since the previous survey, and the area enclosed by the contour is 64,000 m^2. The apparent increase in area from previous surveys was probably caused by better lateral resolution rather than an actual change in area. In fact, Survey V was the first survey for which the sampling resolution in the disposal area was adequate to reliably define the area of the three-dyed-sand-grain contour. The small downstream extension of the tagged material (about 50 m) that was noted for the previous survey was still apparent. In fact, the evidence for this extension was strengthened by three sampling locations along the transect at the downstream end of the three-dyed-sand-grain contour having three or more dyed sand grains. The fact that three locations rather than only one contained dyed sand was probably a consequence of the greater sampling resolution and not an indication of additional lateral spreading.

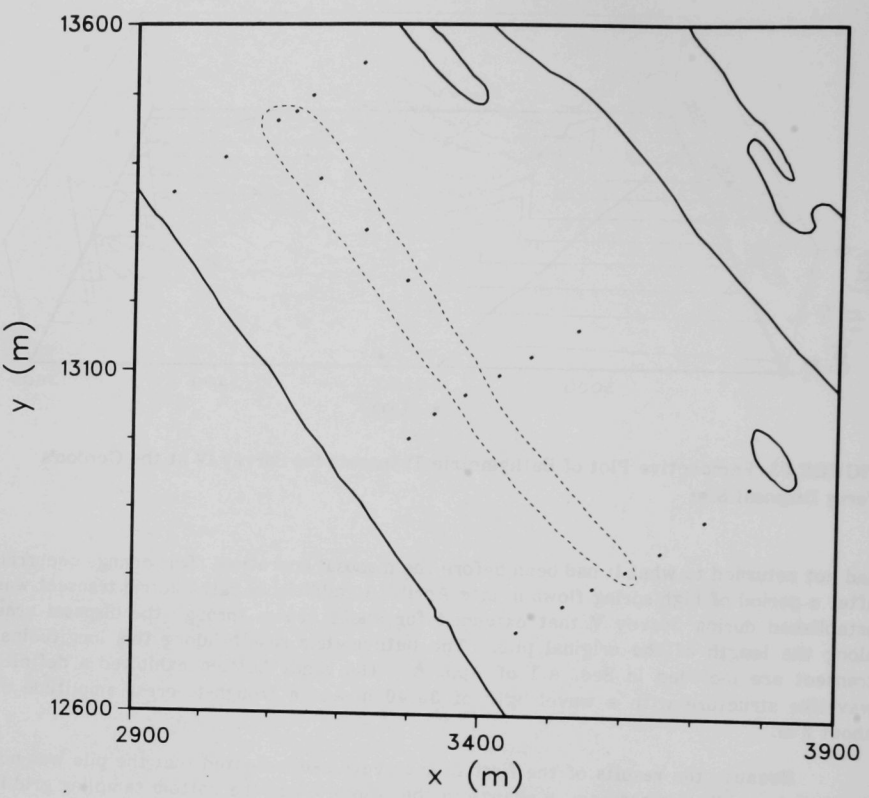

FIGURE 24 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey IV at the Gordon's Ferry Disposal Site

On Survey V single dyed sand grains were found at stations on a transect about 1500 m downstream of the original disposal area. Two dyed sand grains were found in Stone Slough (see Sec. A.2 in App. A for their locations). The classification of bottom sediments (see Fig. 3.28) appeared to be similar to that found for Survey IV, with both surveys indicating a trend toward somewhat coarser material.

In Survey V little change had occurred in the distribution of tagged sand. But, apparently in response to high flows, the original pile was no longer distinguishable as a separate bed form among sand dunes in the disposal area. Single dyed sand grains were found at stations farther downstream than before, and the first evidence was found of any dyed sand (two grains) in Stone Slough. The bottom sediments continued the trend toward somewhat coarser material than found in earlier surveys.

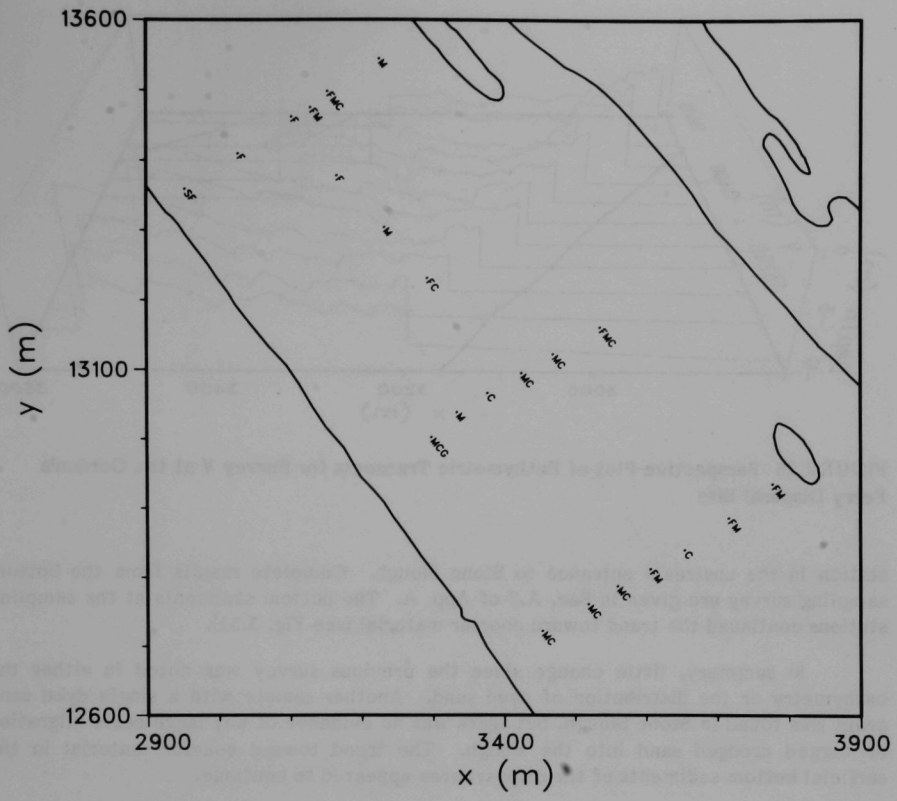

FIGURE 25 Approximate Classification of Bottom Sediments at Sampling Locations for Survey IV at the Gordon's Ferry Disposal Site

3.3.5 Survey VI

The bathymetric results of Survey VI (October 12-13, 1982) are shown in Fig. 29 and in Sec. A.1 of App. A. The transverse transects indicated little systematic change during the summer from those of Survey V, although the same wavelike structure present in the longitudinal transect of Survey V remained as evidence of bottom motion.

The higher resolution sampling grid for bottom sampling initiated in Survey V was continued in this survey. No significant change in the location of the three-dyed-sand-grain contour was noted (see Fig. 30), and the area enclosed by the three-dyed-sand-grain contour is 70,000 m^2, approximately the same as in Survey V.

Sampling locations where single dyed sand grains were found extended about 1800 m downstream of the original disposal area. One dyed sand grain was found at a

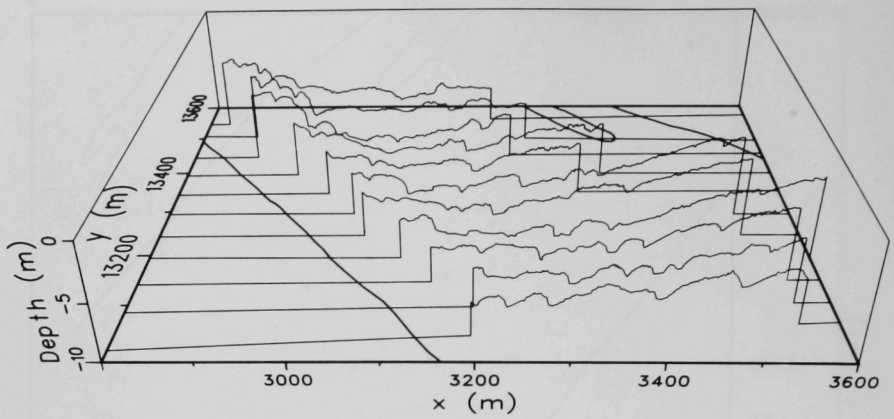

FIGURE 26 Perspective Plot of Bathymetric Transects for Survey V at the Gordon's Ferry Disposal Site

station in the upstream entrance to Stone Slough. Complete results from the bottom sampling survey are given in Sec. A.2 of App. A. The bottom sediments at the sampling stations continued the trend toward coarser material (see Fig. 3.31).

In summary, little change since the previous survey was noted in either the bathymetry or the distribution of dyed sand. Another sample with a single dyed sand grain was found in Stone Slough, but there was no evidence of any large-scale migration of tagged dredged sand into the slough. The trend toward coarser material in the surficial bottom sediments of the disposal area appeared to continue.

3.3.6 Survey VII

Survey VII was conducted June 7-9, 1983, 588 days and two spring flood periods after disposal. It is the last survey at Gordon's Ferry discussed in this report. The results of the additional surveys that have been made will be presented in a subsequent report. The bathymetric results from Survey VII are shown in Fig. 32 and Sec. A.1 of App. A. The transverse transects through the disposal area indicated that the bottom continued to change but had not returned to the elevation that existed before disposal. In fact, the bathymetric results from Surveys V, VI, and VII indicated that the average bottom elevation in the location of the original disposal pile was about a meter higher than it had been at the time of disposal. Four additional longitudinal bathymetric transects were added during Survey VII, two on either side of the transect established during Survey V and about 40 m apart. All five transects exhibited the same wavelike structure observed in Surveys V and VI.

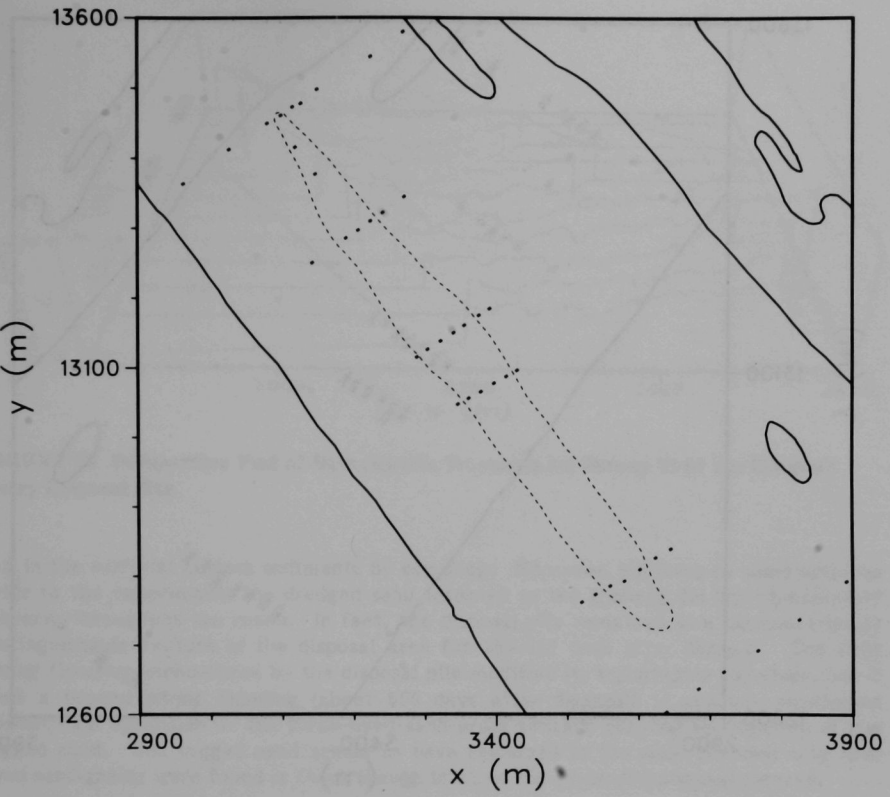

FIGURE 27 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey V at the Gordon's Ferry Disposal Site

Results of the bottom sampling indicated a rather dramatic change since the previous survey. In Survey VII the three-dyed-sand-grain contour (see Figs. 33 and 34) extended about 1000 m further downstream than in Survey VI, essentially doubling the downstream extent of the contour. The area enclosed by the contour had also doubled, from 70,000 m^2 to 144,000 m^2. This downstream extension of the contour and doubling of the area of tagged sand was probably caused by the protracted flooding that occurred from about mid-March to June 1983 (see Fig. 10).

One dyed sand grain was found in Stone Slough on Survey VII, and single dyed sand grains were found on the last bottom sampling transect downstream, about 1900 m from the original pile. The classification of bottom sediments in the disposal area (see Fig. 35) indicated a virtual absence of fine sand. The surficial bottom was composed almost entirely of medium and coarse sand.

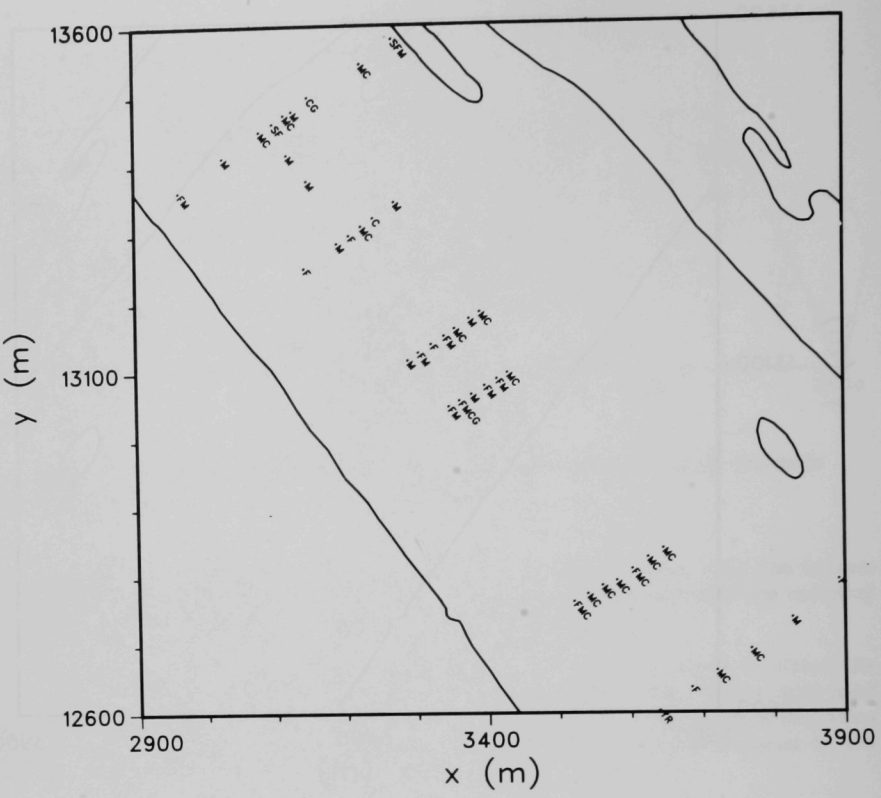

FIGURE 28 Approximate Classification of Bottom Sediments at Sampling Locations for Survey V at the Gordon's Ferry Disposal Site

During Survey VII, the first evidence of large-scale migration of the tagged dredged sand was evidenced by a downstream extension of the three-dyed-sand-grain contour of about 1000 m and a doubling of the enclosed area. As in earlier surveys, no large-scale movement of dyed sand into Stone Slough was noted, although one grain was found at one sampling location there. Little change of significance in the bathymetric data had occurred since Survey VI, and the wavelike structure apparent during previous surveys continued. The surficial bottom sediments in the disposal area were composed almost entirely of medium to coarse sand.

3.4 SUMMARY OF GORDON'S FERRY RESULTS

The experiment at Gordon's Ferry demonstrated the feasibility of large-scale tagging of dredged material prior to disposal and subsequent detection of the dyed sand

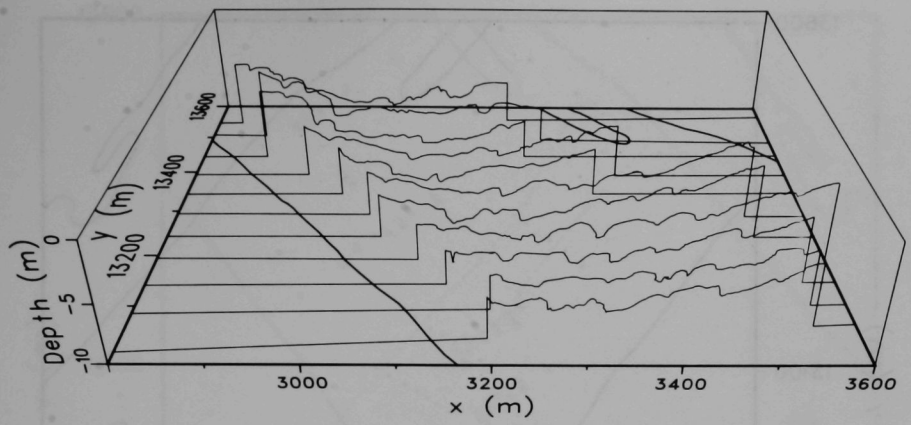

FIGURE 29 Perspective Plot of Bathymetric Transects for Survey VI at the Gordon's Ferry Disposal Site

tag in the surficial bottom sediments by sampling. Moreover, contrary to some opinions prior to the experiment, the dredged sand returned to the thalweg did not immediately disperse throughout the reach. In fact, the disposal pile remained as a bathymetrically distinguishable feature in the disposal area for 153-217 days after disposal. The first spring flooding encountered by the disposal pile modified its topographic signature, but it took a second spring flooding (about 550 days after disposal) to produce significant downstream extension of the three-dyed-sand-grain contour defining the location of the tagged sand. The tagged sand seems to have remained in the main channel; only four dyed sand grains were found in Stone Slough in all of the seven postdisposal surveys.

At Gordon's Ferry, the Argonne experimental plan was originally designed to identify any large-scale migration of tagged sand from the original disposal area into main-channel border areas, backwaters, or sloughs. As it became apparent that large-scale migration was not occurring, the plan was modified to focus more on measurements in the vicinity of the disposal pile. In addition to bottom sampling for dyed sand, measurements of bathymetry and characterization of bottom sediments were important to understanding the changes taking place in the disposal area.

The results of the bathymetric measurements indicated that the bottom topography in the disposal area returned to a form that was probably similar to what existed prior to disposal. No significant changes were noted in the bottom topography from the time of disposal until Survey V. The results of bathymetric measurements from Survey V showed that the original disposal pile no longer existed as a bed form distinguishable from other bed forms. In addition, longitudinal bathymetric transects indicated the existence of wavelike structures on the sandy bottom, with nominal wavelengths of 30-40 m and trough-to-crest amplitudes of 1-2 m. The average bottom elevation, however, had not returned to the depth that existed prior to disposal,

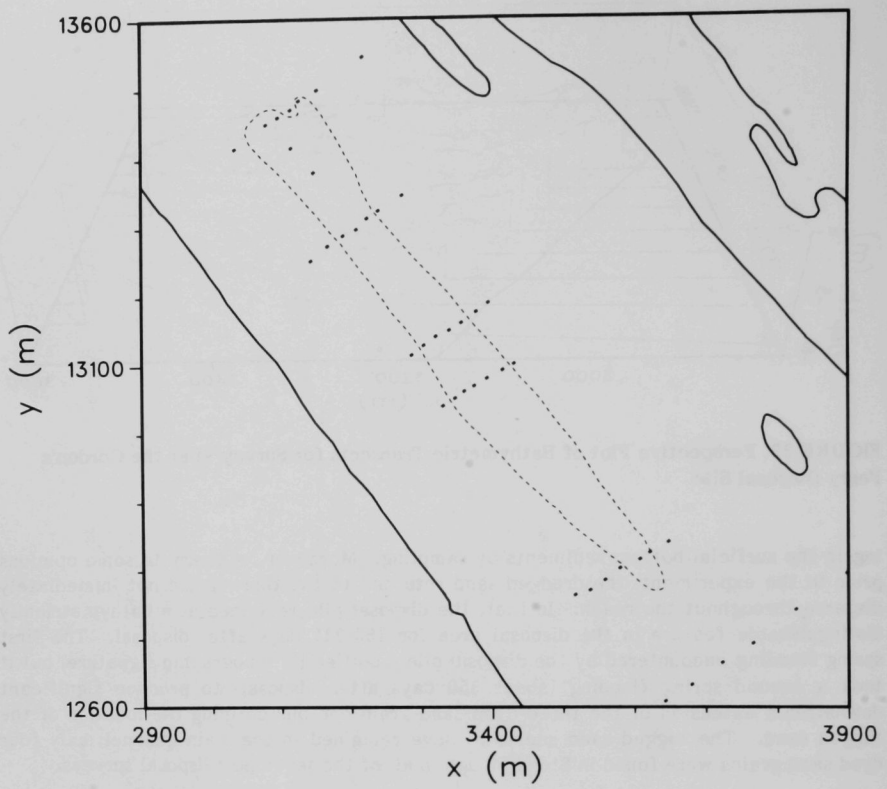

FIGURE 30 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey VI at the Gordon's Ferry Disposal Site

remaining about 1 m higher. No significant change to the bottom took place between Survey V and Survey VII. In general, it appeared that the elongated mound that was formed during the disposal operation evolved into wavelike bottom structures that apparently are the usual type of bed form that exists in the river bottom.

Although the area containing measurable amounts of dyed sand (≥3 grains per bottom sample) did not appear to change significantly for the first six surveys, the area within the three-dyed-sand-grain contour doubled between Surveys VI and VII. This increase is indicated in Table 3, which shows the area enclosed by the three-dyed-sand-grain contour for the seven surveys. While the bottom sampling grids used in Surveys I-IV were of fairly low resolution, yielding only very approximate estimates of the area of the three-dyed-sand-grain contour, the higher resolution grids used in Surveys V-VII provided well-defined contours and more accurate areas. The table confirms that the area

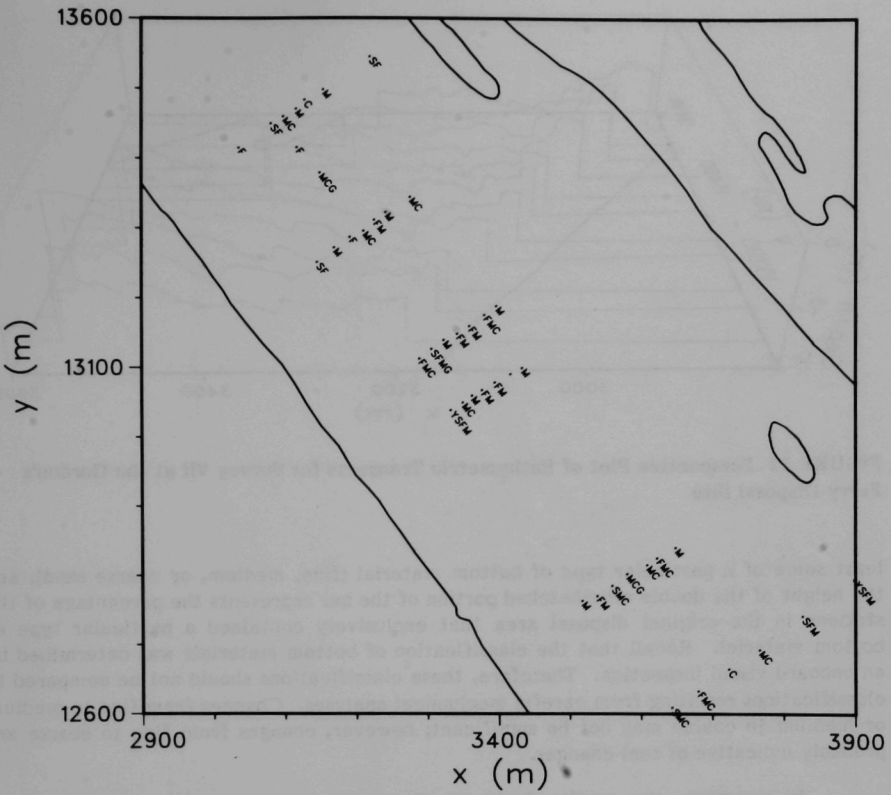

FIGURE 31 Approximate Classification of Bottom Sediments at Sampling Locations for Survey VI at the Gordon's Ferry Disposal Site

enclosed by the contour did not change significantly until after Survey VI, when the area doubled.

Examination of surficial bottom sediments in the disposal area indicated a gradual change from fine sand immediately after disposal to coarser sand. Figure 36 summarizes the sediment characteristics at sampling locations in the original disposal area as they changed from survey to survey. Specifically, the data used to generate this figure came from the area bounded in the north-south direction by the limits of the topographically distinguishable pile and in the transverse direction by the initial three-dyed-sand-grain contour (see Fig. 15).

Two quantities are plotted in Fig. 36. The height of the bar represents the percentage of the stations in the original disposal area on each survey that contained at

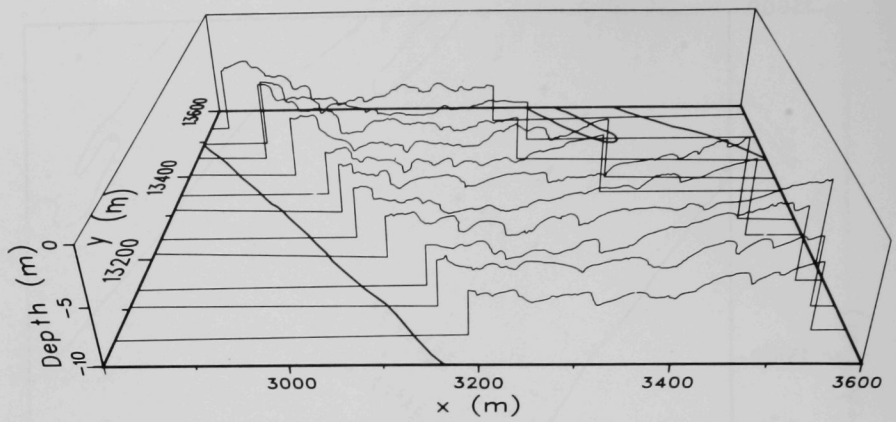

FIGURE 32 Perspective Plot of Bathymetric Transects for Survey VII at the Gordon's Ferry Disposal Site

least some of a particular type of bottom material (fine, medium, or coarse sand), and the height of the double crosshatched portion of the bar represents the percentage of the stations in the original disposal area that exclusively contained a particular type of bottom material. Recall that the classification of bottom materials was determined by an onboard visual inspection. Therefore, these classifications should not be compared to classifications resulting from careful mechanical analyses. Changes from fine to medium or medium to coarse may not be significant; however, changes from fine to coarse are probably indicative of real changes.

In summary, the results from the first seven surveys at the Gordon's Ferry disposal site indicated the following:

1. No evidence was found of large-scale migration of dredged sand into biologically sensitive main-channel borders, backwaters, or sloughs.

2. The disposal pile, which was originally quite distinct bathymetrically, lost its topographic signature after the first spring flood and eventually evolved into channel bed forms.

3. The area of tagged sand, as defined by the three-dyed-sand-grain contour, showed little movement until after Survey VI when it elongated by a factor of two with a corresponding doubling in area, probably in response to flooding.

4. The type of bottom sediment found in the original disposal area gradually changed from fine to coarse sand.

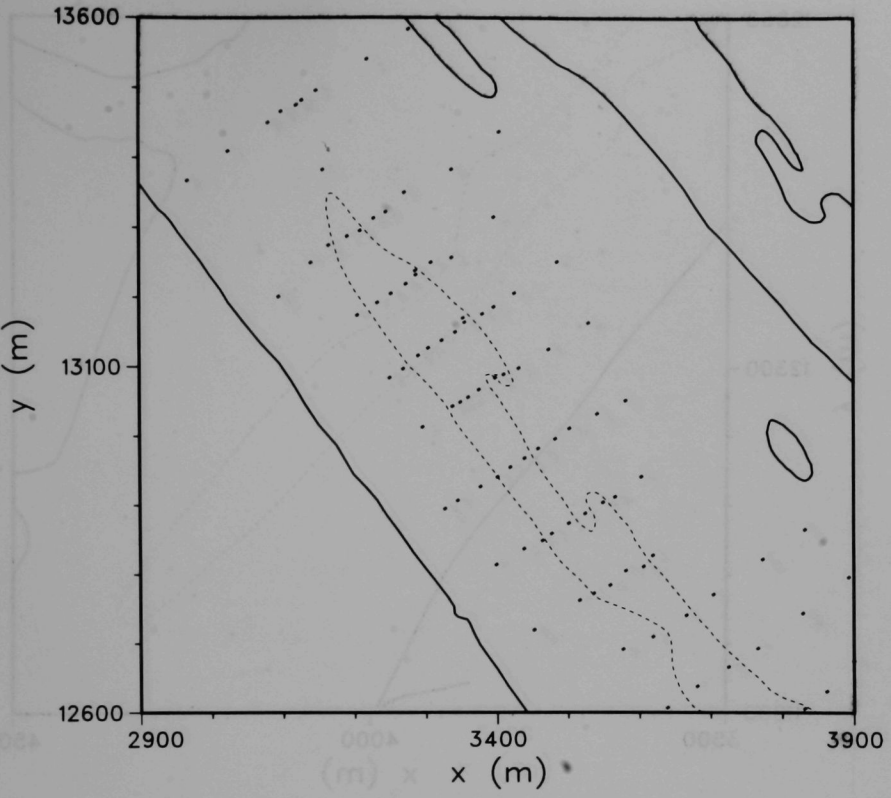

FIGURE 33 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey VII at the Gordon's Ferry Disposal Site

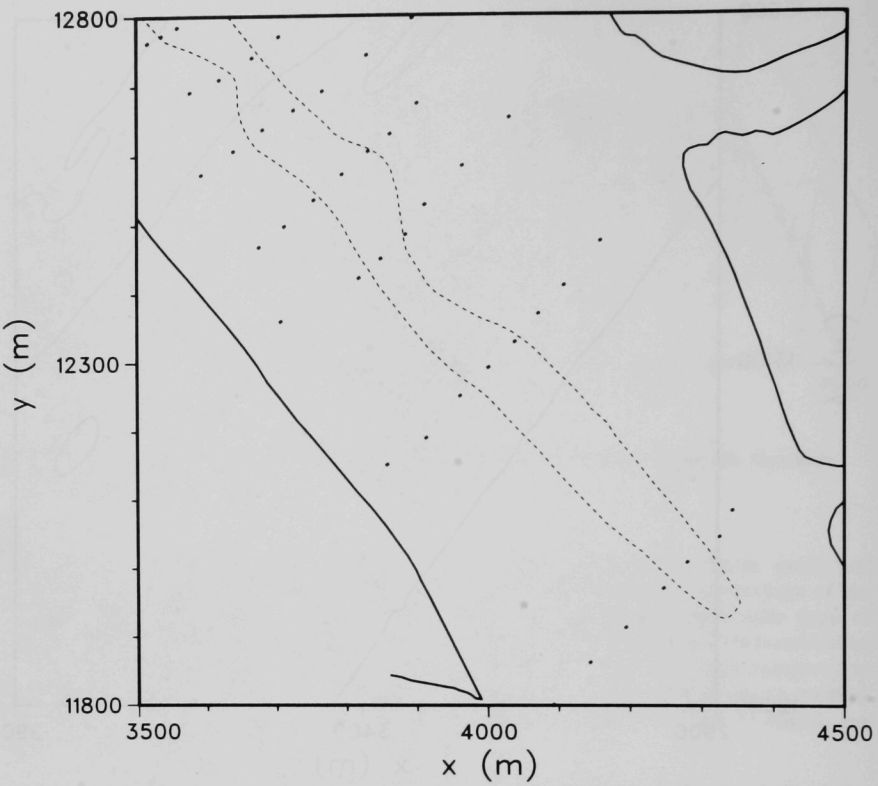

FIGURE 34 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey VII Downstream of the Gordon's Ferry Disposal Site

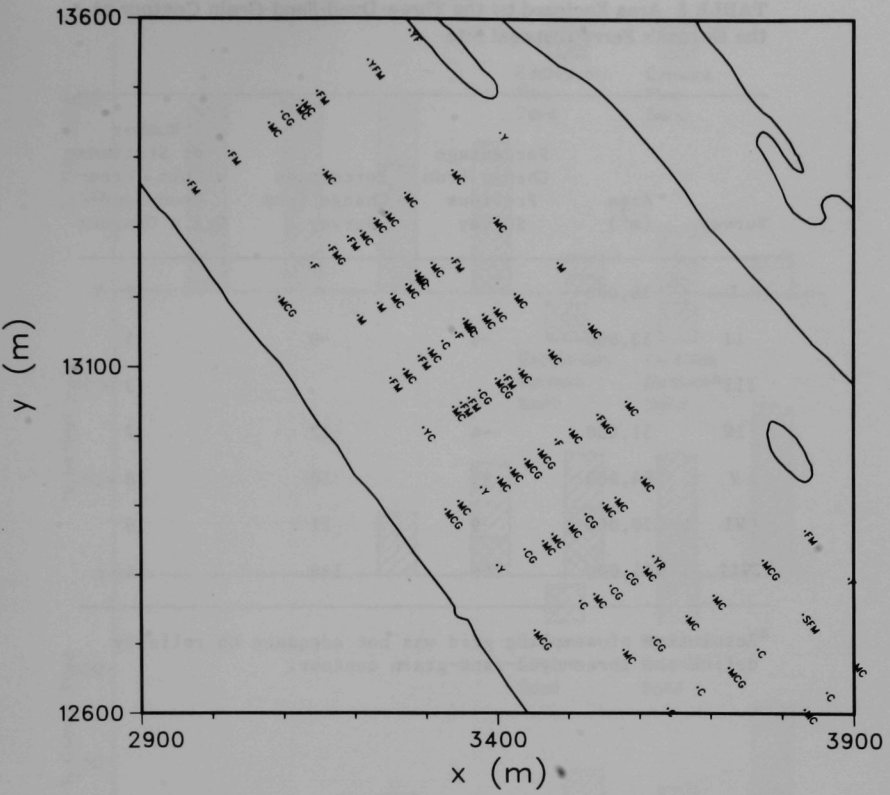

FIGURE 35 Approximate Classification of Bottom Sediments at Sampling Locations for Survey VII at the Gordon's Ferry Disposal Site

TABLE 3 Area Enclosed by the Three-Dyed-Sand-Grain Contour at the Gordon's Ferry Disposal Site

Survey	Area (m^2)	Percentage Change from Previous Survey	Percentage Change from Survey I	Number of Stations within Three-Dyed-Sand-Grain Contour
I	58,000			12
II	53,000	-9	-9	5
III[a]				3
IV	51,000	-4	-12	7
V	64,000	25	10	18
VI	70,000	9	21	19
VII	144,000	106	148	34

[a]Resolution of sampling grid was not adequate to reliably define the three-dyed-sand-grain contour.

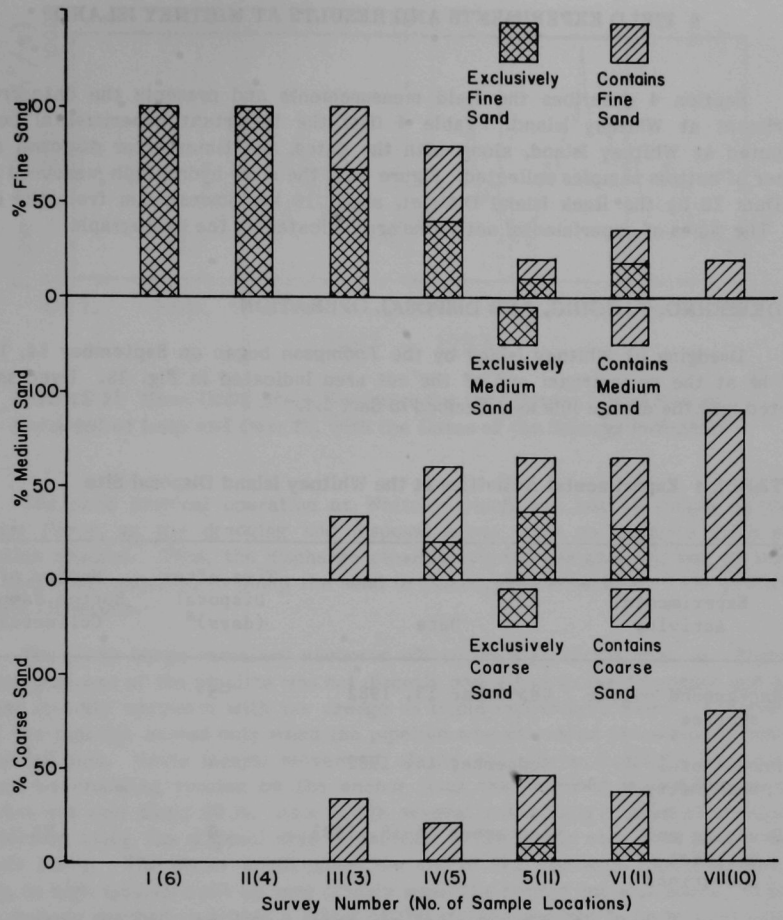

FIGURE 36 Bottom Sediment Classification in the Disposal Area at the Gordon's Ferry Site for Each Survey

4 FIELD EXPERIMENTS AND RESULTS AT WHITNEY ISLAND

Section 4 describes the field measurements and presents the data from the experiment at Whitney Island. Table 4 lists the important experimental activities conducted at Whitney Island, along with the dates, the times after disposal, and the number of bottom samples collected. Figure 37 is the river hydrograph measured at Lock and Dam 22 by the Rock Island District, about 19 km downstream from the disposal site. The times of experimental activities are indicated on the hydrograph.

4.1 DREDGING, TAGGING, AND DISPOSAL OPERATION

Dredging at Whitney Island by the *Thompson* began on September 14, 1982, at 2347 hr at the downstream end of the cut area indicated in Fig. 38. Dyed sand was injected into the dredge line as described in Sec. 2.1.

TABLE 4 Experimental Activities at the Whitney Island Disposal Site

Experimental Activity	Date	Time after Disposal (days)[a]	Number of Bottom Samples Collected
Background bottom samples	September 13, 1982	-5	9
Predisposal bathymetry	September 14, 1982	-4	NA[b]
Dredging and disposal operations	September 14-18, 1982	0	NA
Survey I	September 18-21, 1982	0	115
Survey II	September 28-29, 1982	10	69
Survey III	October 26-27, 1982	38	70
Survey IV	January 5-7, 1983	109	143
Survey V	May 24-26, 1983	249	161

[a]Time from the end of disposal operations on September 18, 1982.

[b]Not applicable.

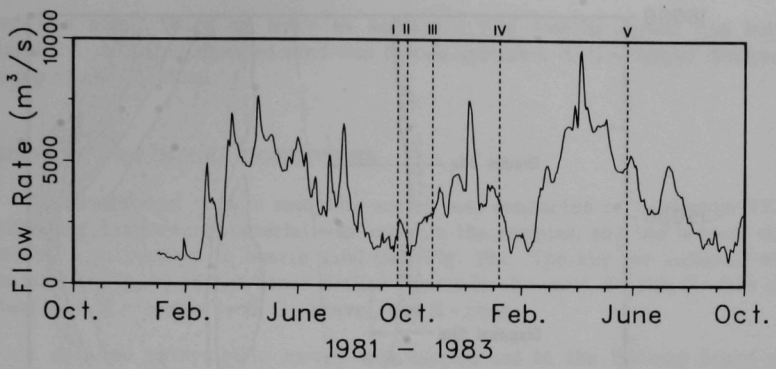

FIGURE 37 Mean Daily River Discharge for the Whitney Island Site as Recorded at Lock and Dam 22, with the Dates of the Surveys Indicated

The sand disposal operation at Whitney Island was not as simple as that at Gordon's Ferry, as the dredging and disposal areas were on opposite sides of the navigation channel. Thus, the discharge pipeline crossed the channel, and an auxiliary pump barge was required to pump the sand to the disposal area about 1 km downstream from the *Thompson*.

The pump barge remained anchored off to the side of the channel. Therefore, the discharge end of the pipeline was not directly connected to the *Thompson* and did not progress steadily upstream with the dredge as it did at Gordon's Ferry. The discharge end of the pipeline moved only when the pipeline was shortened by removing individual sections of pipe. Some lateral movement of the end of the discharge pipe could be effected by changing tension on the anchor lines that secured it, but the maximum excursion was only about 30 m. As a result, several overlapping mounds of dredged sand were formed along the disposal area in contrast to the single elongated pile formed at Gordon's Ferry. The water depth under the end of the discharge pipe was monitored closely, as high mounds built up very quickly when the dredge cut was heavy. In several cases, mounds reached to within a meter of the surface and had to be leveled with prop wash from a moderately sized towboat.

The sand that was dyed for the tagging procedure was from an old river deposit about 1.5 km from the present river near Muscatine, Iowa. A sieve analysis of the sand, prior to dyeing, indicated that the median grain size, d_{50}, was about 0.58 mm; the geometric mean grain size, d_g, was about 0.65 mm; and the geometric standard deviation, σ_g, was about 1.9. In general, the sand would be classified as medium. The sand was dyed by the Rock Island District in the manner described in Sec. 2.1.

The average initial concentration, by weight, of dyed sand was about 90 ppm. This estimate was based on the nominal (maximum) pumping specifications for the *Thompson* (19,000 m^3/day), the total amount of dyed sand injected (about 6500 kg or 4 m^3), and the total time of dyed sand injection (56.6 hr). Thus, the initial dyed sand

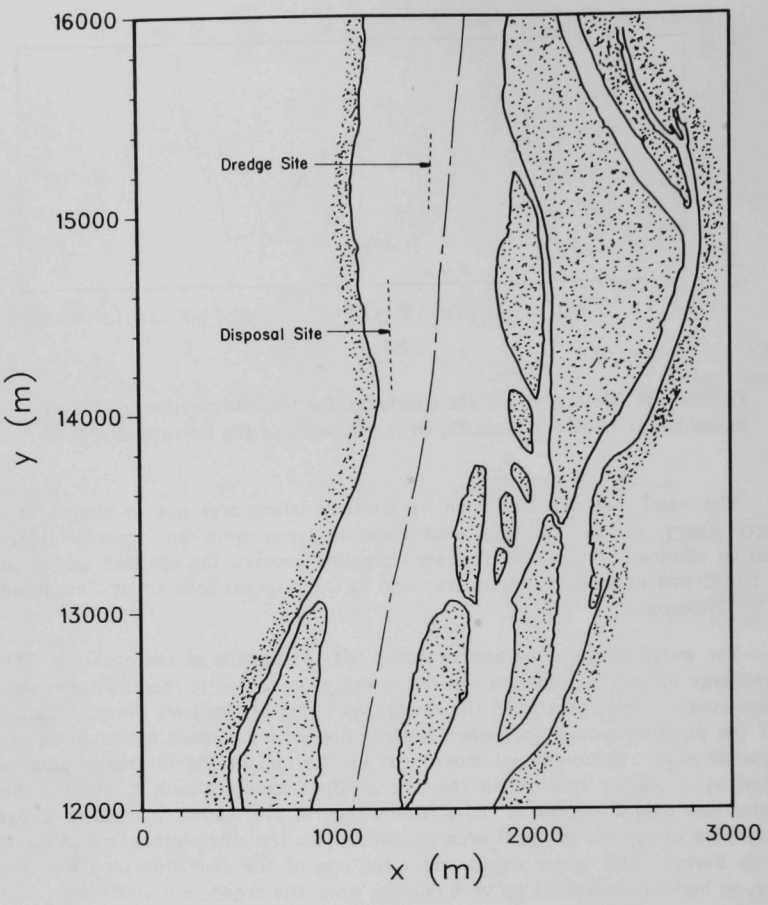

FIGURE 38 Map of the Whitney Island Site Showing Dredging and Disposal Areas

concentration in the Whitney Island experiment (90 ppm) was only about 10% of that in the Gordon's Ferry experiment (1000 ppm).

The dyed sand concentration achieved at Whitney Island (90 ppm) was at about the minimum level needed to identify and track the dredged sand based on the experience at Gordon's Ferry and the statistics of the sampling process as described in Sec. 2.3. However, to maintain this concentration with the available dyed sand, only about half of the sand dredged at the Whitney Island site was tagged. Bathymetric surveys by the District immediately prior to the start of dredging indicated that the volume to be

dredged was about twice as large as surveys a few months earlier had indicated. Consequently, untagged dredged sand was placed upstream of the tagged dredged sand, with a gap of about 100 m.

4.2 SURVEY I AND INITIAL CONDITIONS

The predisposal bottom sampling survey was conducted on September 13, 1982. No interfering fluorescent material was noted in the samples, and the bottom material was generally as medium to coarse sand (see Fig. 39). The key for sediment classifications used in Fig. 39 and all other similar figures is: Y - mud, S - silt, F - fine sand, M - medium sand, C - coarse sand, G - gravel, and R - rock.

A detailed bathymetric survey was carried out at the Whitney Island site on September 14, 1982, a few hours before the beginning of dredging. Fourteen east-west (transverse) transects about 500 m long and 50 m apart were established in the proposed disposal area. Figure 40 shows the results for these transects in the form of a perspective plot, with the base of the plot taken arbitrarily at a depth of 10 m. The direction of flow of the river is from the top to the bottom of the plot. The gap in the data at the western end of the fourth and fifth transects (numbered from the upstream end) can be attributed to the presence of a submerged rock wing dam extending from the west bank of the river at that location. The results from the individual transects are included in Sec. B.1 of App. B.

Immediately following the dredging and disposal operation, another bathymetric survey (Survey I) was made on September 18, 1981, which included essentially the same 14 east-west transects. Because of the difficulty in maintaining a specific boat course in the presence of river currents and winds, the transects did not coincide exactly from survey to survey. The transects were typically within 5-10 m of each other, but deviations of as much as 20 m did occur between surveys. As a result, detailed comparisons between corresponding transects for different surveys may not be valid. The results of this first postdisposal bathymetric survey are shown in Fig. 41 and are included in Sec. B.1 of App. B.

Evidence of the pile formed by the disposal operation can be seen in all but the southernmost transect and the two transects near the wing dam. In general, the peak of the pile was located between x = 1260 m and x = 1300 m. The pile extended downstream from about y = 14,700 m to about y = 14,100 m, for a total length of about 600 m. The average water depth in this region ranged from 5.7 m to 7.3 m before disposal. The pile was not uniform over its length and appeared to consist of a series of overlapping mounds of various heights and widths. The height of the disposal pile above the local natural bottom, based on the predisposal bathymetric survey of September 14, 1982, ranged from 0.7 m to 5.3 m, with an average height of 3.0 m. The width of the pile at the base ranged from 40 m to 80 m, with an average width of about 60 m.

In addition to the 14 east-west transects, five north-south transects about 50 m apart were established in the vicinity of the disposal area during the first postdisposal survey. The bathymetric results from these transects (see Sec. B.1 of App. B) showed an irregular bottom in the region of the disposal pile. However, the results of the transect

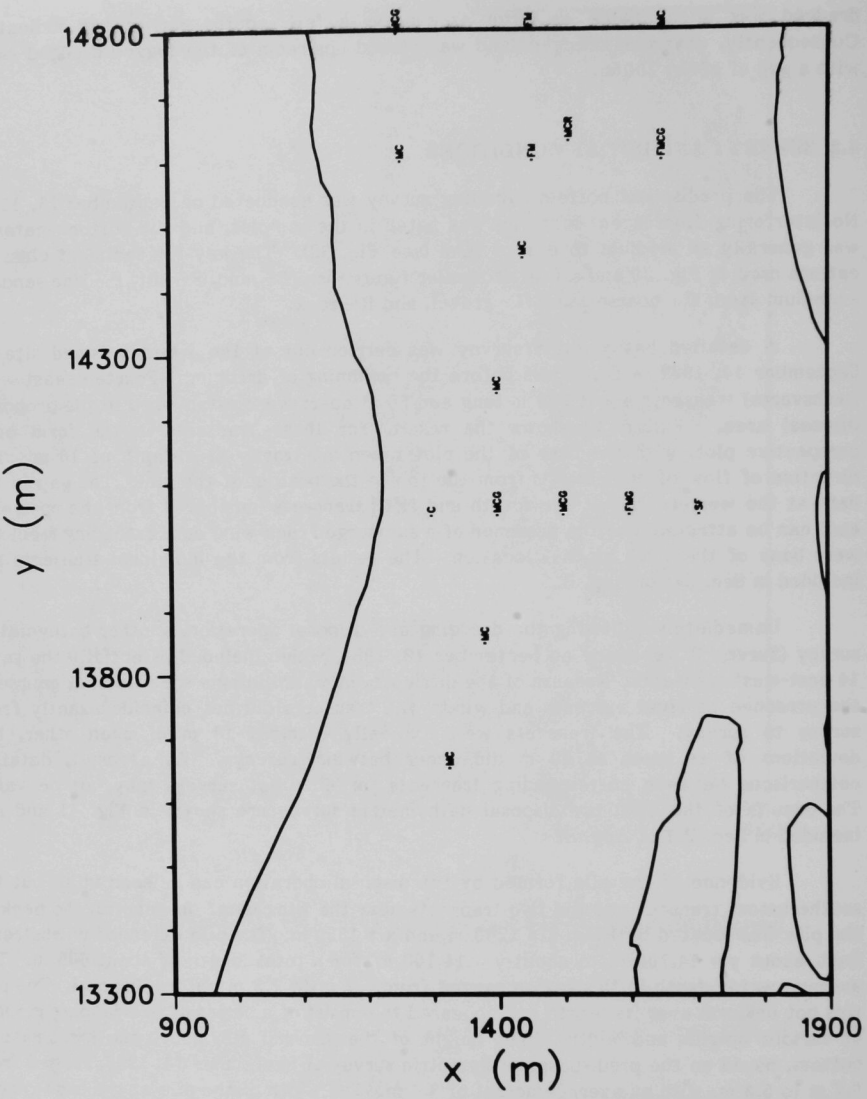

FIGURE 39 Approximate Classification of Bottom Sediments at Sampling Locations during the Predisposal Survey at the Whitney Island Disposal Site

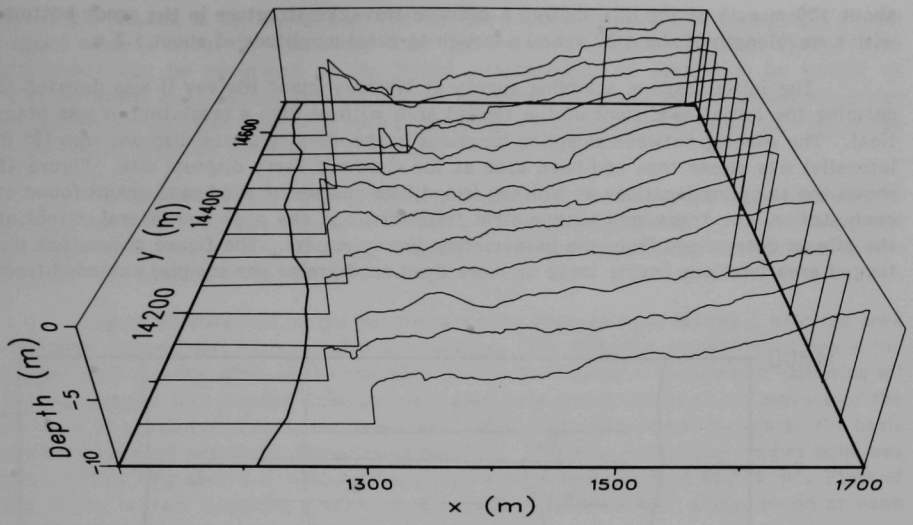

FIGURE 40 Perspective Plot of Bathymetric Transects for Predisposal Survey at the Whitney Island Disposal Site

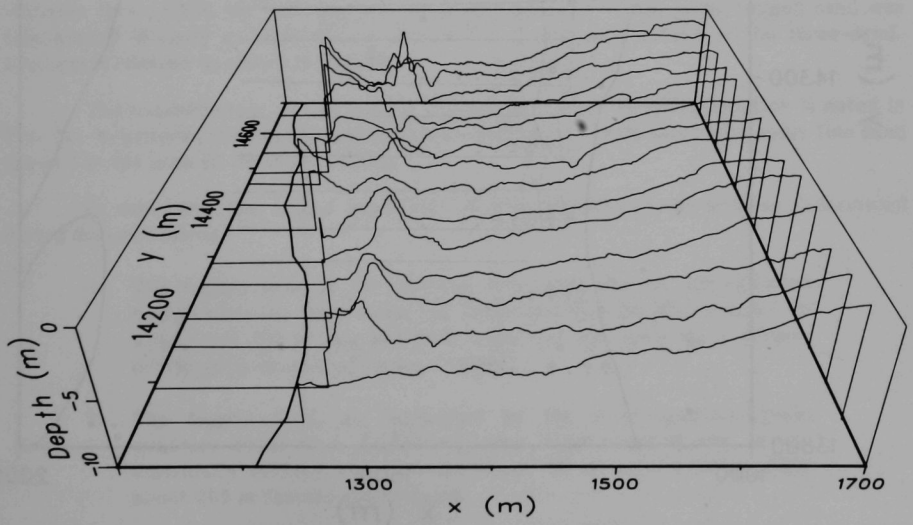

FIGURE 41 Perspective Plot of Transverse Bathymetric Transects for Survey I at the Whitney Island Disposal Site

about 100 m east of the pile showed a definite wavelike structure in the sandy bottom, with a wavelength of about 32 m and a trough-to-crest amplitude of about 1.3 m.

The initial bottom sampling survey at Whitney Island (Survey I) was devoted to defining the initial conditions of the tagged area with as high a resolution as was practical. The spacing between sampling locations in the vicinity of the disposal area (25 m laterally) was closer than had been used at the Gordon's Ferry disposal site. Figure 42 shows the sampling locations at Whitney Island, the number of dyed sand grains found at each station, the transverse bathymetric transects, and the peak and lateral extent of the pile as determined from the bathymetric survey results. The figure shows that the tagged area (stations having three or more dyed sand grains per sample) extended from

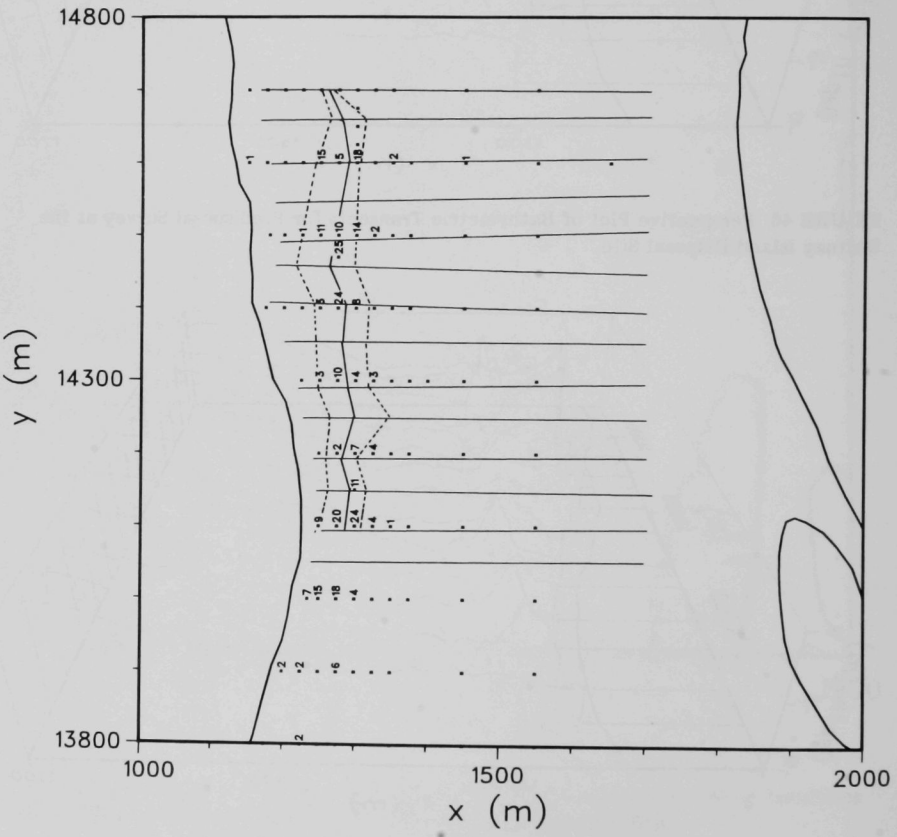

FIGURE 42 Location of Bathymetric Transects and Bottom Sampling Stations for Survey I at the Whitney Island Disposal Site (location of the pile and the number of dyed sand grains observed are noted)

about y = 14,600 m to 13,900 m. The number of dyed sand grains per sample in the tagged area is about 20 times less than was found initially at Gordon's Ferry. This difference can be explained by the initial concentration of dyed sand by weight at Whitney Island being about 10% of that at Gordon's Ferry and by the geometric mean grain size for the dyed sand at Whitney Island (d_g = 0.65 mm) being larger than the mean grain size at Gordon's Ferry (d_g = 0.40 mm).

The area of tagged sand at Whitney Island extended about 200 m downstream of the pile as defined by the results of the bathymetric survey. As at Gordon's Ferry, this downstream extension was probably caused by dredged sand being transported downstream while settling to the bottom.

Figure 43 shows all of the bottom sampling stations from Survey I, with the area enclosing most of the tagged material indicated. The criterion chosen to delineate the tagged sand was the same as the one used for Gordon's Ferry -- the contour enclosing all bottom samples that yielded three or more dyed sand grains visible on the surface of the 23 cm x 23 cm sample tray. The three-dyed-sand-grain contour was chosen on the basis of the statistical argument discussed in Sec. 2.3. The area containing tagged sand was about 700 m long and 75 m wide, and enclosed a total area of about 54,000 m^2. Plots of the entire bottom sampling grid, with the number of dyed sand grains found at each location indicated, are included in Sec. B.2 of App. B.

Downstream sampling was continued until a transect was completed where no dyed sand was noted by visual onboard inspection of the bottom samples. However, later inspection of the photographs revealed a dyed sand grain in a sample from the last transect (y = 13,500 m) that was not noted in the field. Thus, some tagged sand was transported initially at least 400 m beyond the downstream extent of the three-dyed-sand-grain contour as shown in Fig. 43.

The classification of the bottom sediments at each sampling location is noted in Fig. 44. In general, the bottom material was medium to coarse sand, with some fine sand present in the area of the disposal pile.

In summary, the initial conditions of the tagged disposal area as determined during Survey I were:

1. The tagged sand in the disposal area that can be distinguished bathymetrically from other bed forms (termed the pile) covered an area about 600 m long and 60 m wide, and was made up of several overlapping mounds of various heights.

2. The tagged sand, as delineated by the three-dyed-sand-grain contour, covered a 54,000-m^2 area that included the bathymetrically defined pile but was about 15 m wider and extended about 200 m farther downstream.

3. Single dyed sand grains were found as far as 400 m downstream of the three-dyed-sand-grain contour.

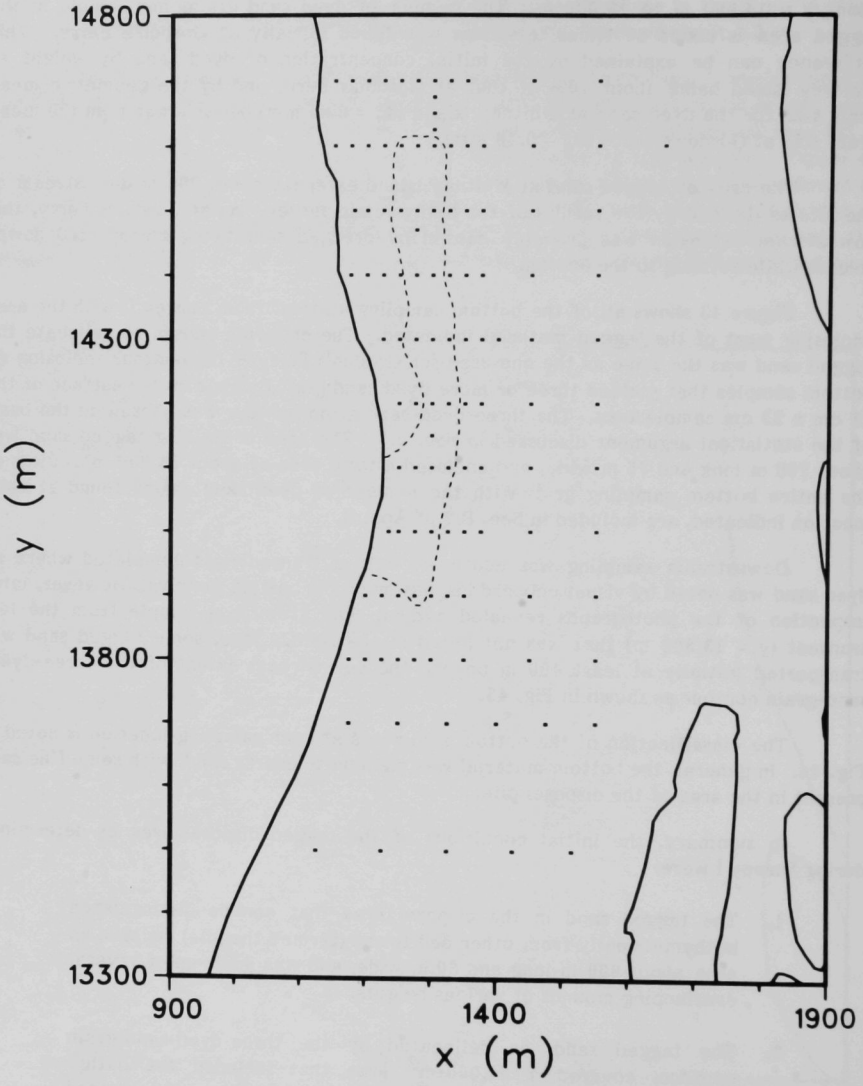

FIGURE 43 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey I at the Whitney Island Disposal Site

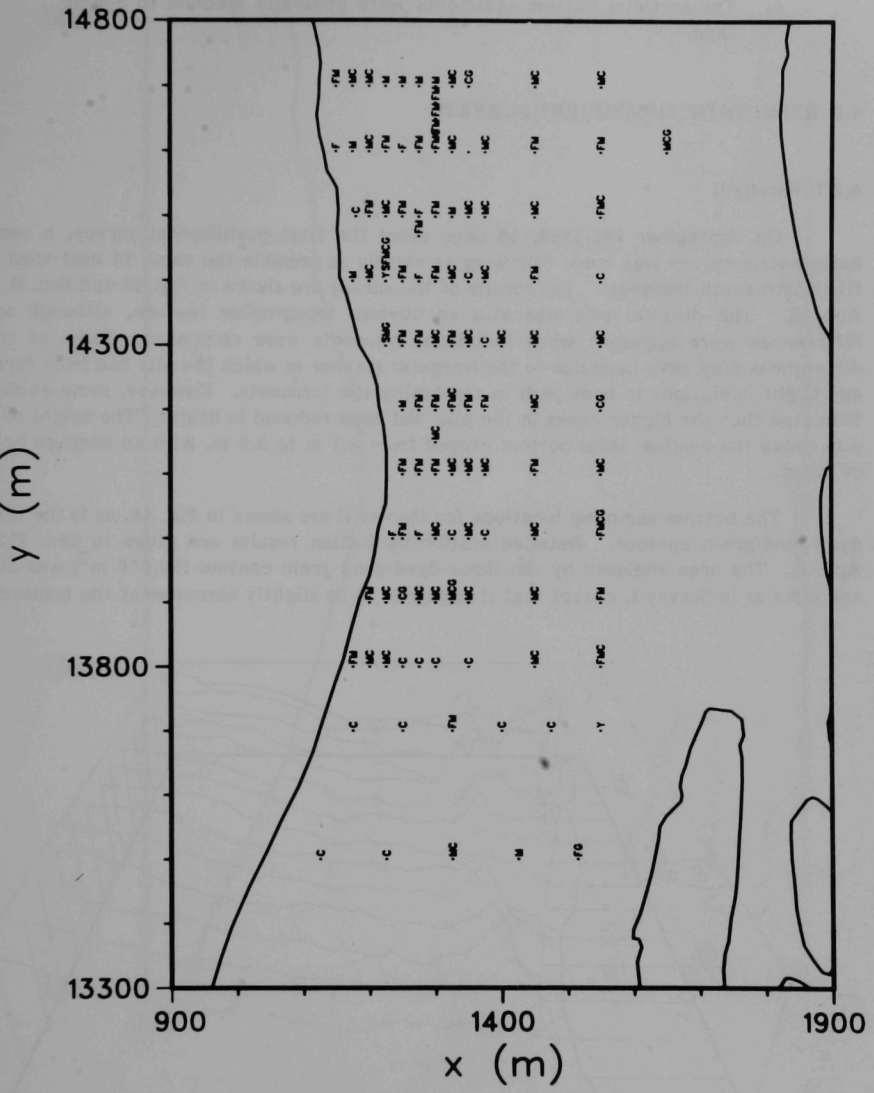

FIGURE 44 Approximate Classification of Bottom Sediments at Sampling Locations for Survey I at the Whitney Island Disposal Site

4. The surficial bottom sediments were generally medium to coarse sand.

4.3 RESULTS OF SUBSEQUENT SURVEYS

4.3.1 Survey II

On September 28, 1982, 10 days after the first postdisposal survey, a second bathymetric survey was made following as closely as possible the same 14 east-west and five north-south transects. The results of the survey are shown in Fig. 45 and Sec. B.1 of App. B. The disposal pile was still an obvious topographic feature, although some differences were apparent when individual transects were compared. Some of these differences may have been due to the irregular manner in which the pile had been formed and slight deviations in boat path in traversing the transects. However, some evidence indicated that the higher peaks in the pile had been reduced in height. The height of the pile above the original local bottom ranged from 0.7 m to 3.5 m, with an average height of 2.5 m.

The bottom sampling locations for Survey II are shown in Fig. 46, as is the three-dyed-sand-grain contour. Detailed station-by-station results are given in Sec. B.2 of App. B. The area enclosed by the three-dyed-sand-grain contour (59,000 m^2) was about the same as in Survey I, except that it appeared to be slightly narrower at the transect at

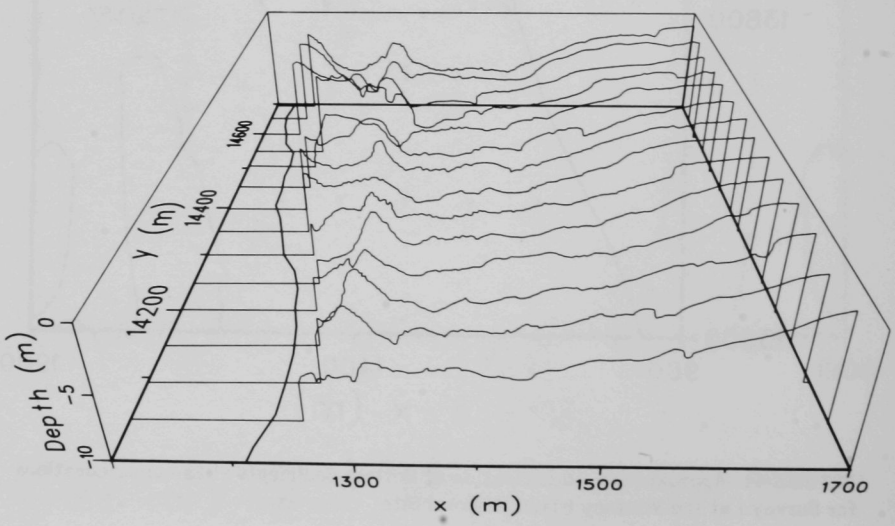

FIGURE 45 Perspective Plot of Transverse Bathymetric Transects for Survey II at the Whitney Island Disposal Site

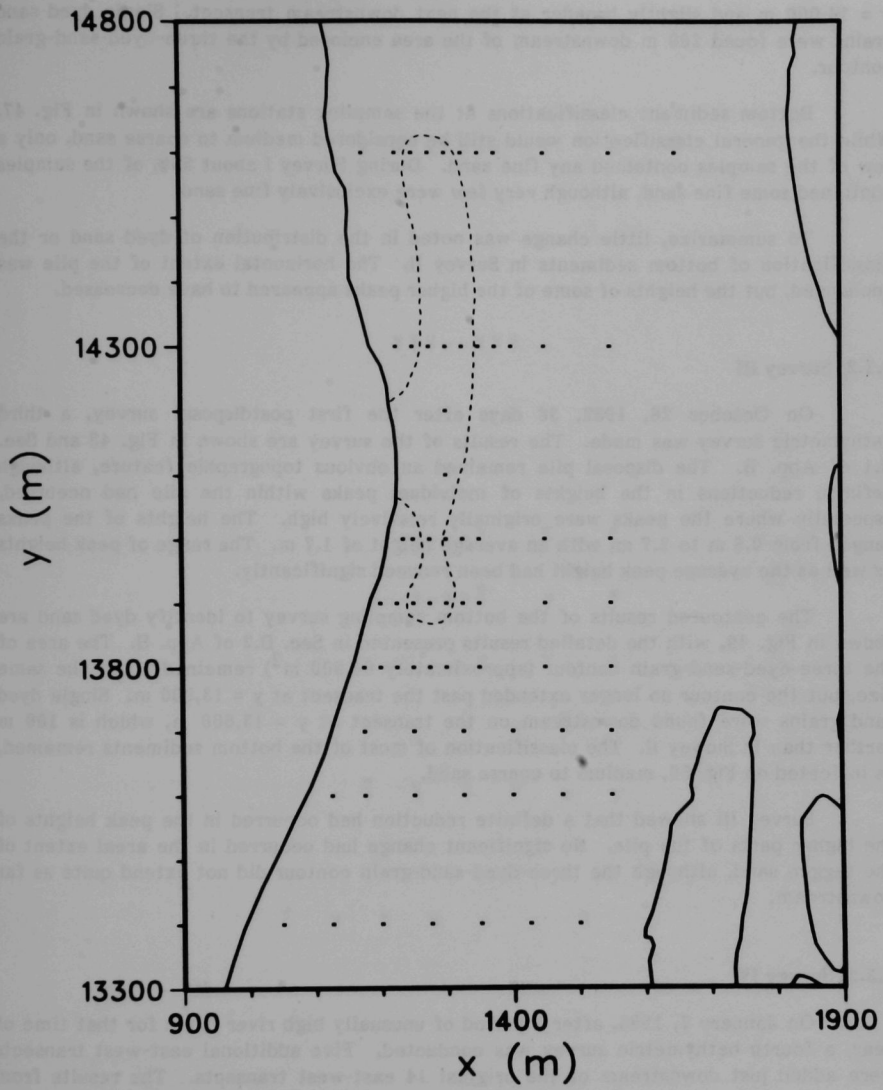

FIGURE 46 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey II at the Whitney Island Disposal Site

y = 14,000 m and slightly broader at the next downstream transect. Single dyed sand grains were found 200 m downstream of the area enclosed by the three-dyed-sand-grain contour.

Bottom sediment classifications at the sampling stations are shown in Fig. 47. While the general classification would still be considered medium to coarse sand, only a few of the samples contained any fine sand. During Survey I about 50% of the samples contained some fine sand, although very few were exclusively fine sand.

To summarize, little change was noted in the distribution of dyed sand or the classification of bottom sediments in Survey II. The horizontal extent of the pile was unchanged, but the heights of some of the higher peaks appeared to have decreased.

4.3.2 Survey III

On October 26, 1982, 38 days after the first postdisposal survey, a third bathymetric survey was made. The results of the survey are shown in Fig. 48 and Sec. B.1 of App. B. The disposal pile remained an obvious topographic feature, although definite reductions in the heights of individual peaks within the pile had occurred, especially where the peaks were originally relatively high. The heights of the peaks ranged from 0.6 m to 2.7 m, with an average height of 1.7 m. The range of peak heights as well as the average peak height had been reduced significantly.

The contoured results of the bottom sampling survey to identify dyed sand are shown in Fig. 49, with the detailed results presented in Sec. B.2 of App. B. The area of the three-dyed-sand-grain contour (approximately 64,000 m^2) remained about the same size, but the contour no longer extended past the transect at y = 13,900 m. Single dyed sand grains were found downstream on the transect at y = 13,600 m, which is 100 m farther than in Survey II. The classification of most of the bottom sediments remained, as indicated on Fig. 50, medium to coarse sand.

Survey III showed that a definite reduction had occurred in the peak heights of the higher parts of the pile. No significant change had occurred in the areal extent of the tagged sand, although the three-dyed-sand-grain contour did not extend quite as far downstream.

4.3.3 Survey IV

On January 7, 1983, after a period of unusually high river flows for that time of year, a fourth bathymetric survey was conducted. Five additional east-west transects were added just downstream of the original 14 east-west transects. The results from some of the transects are shown in Fig. 51, and results from all the transects are included in Sec. B.1 of App. B. The disposal pile was no longer a distinguishable topographic feature in most transects. In fact, the average bottom elevation in the region where the disposal pile had been originally located had returned to about what it had been before the disposal operation. The results from the north-south bathymetric transects (see Sec. B.1 in App. B) also showed evidence of changes in the river bottom.

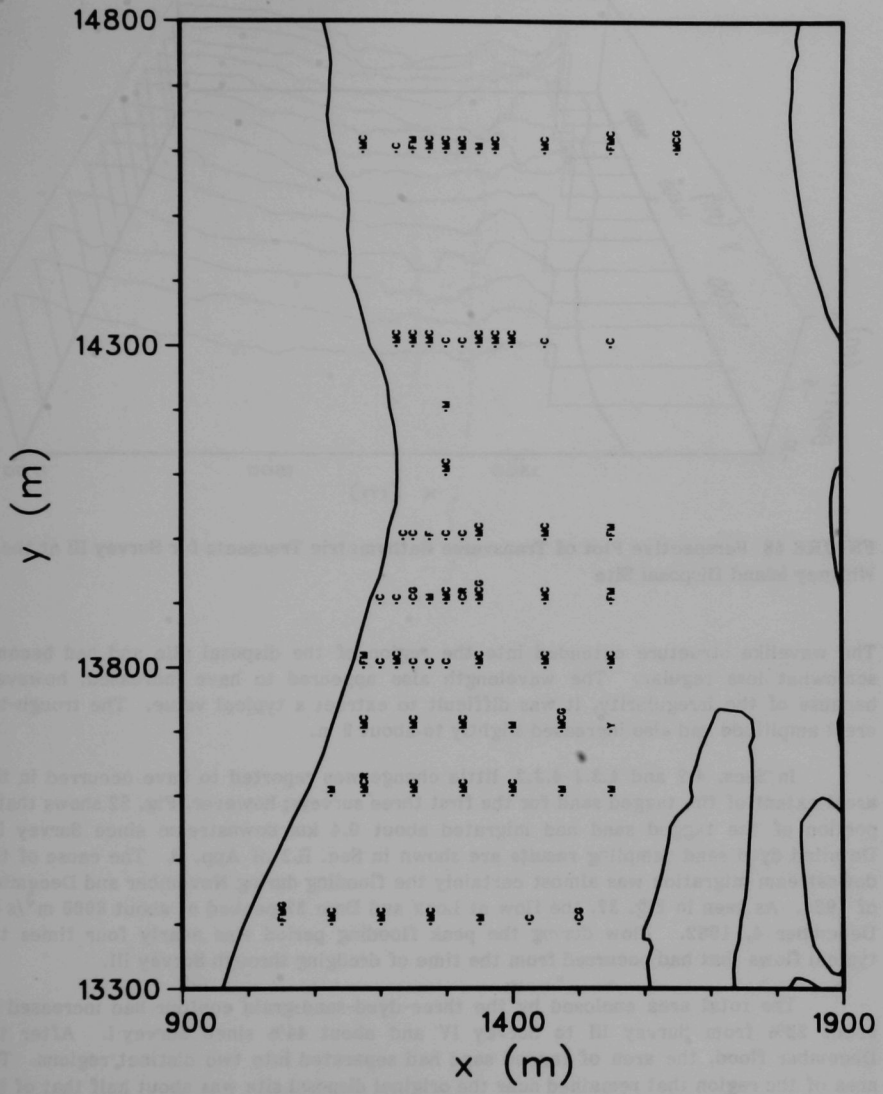

FIGURE 47 Approximate Classification of Bottom Sediments at Sampling Locations for Survey II at the Whitney Island Disposal Site

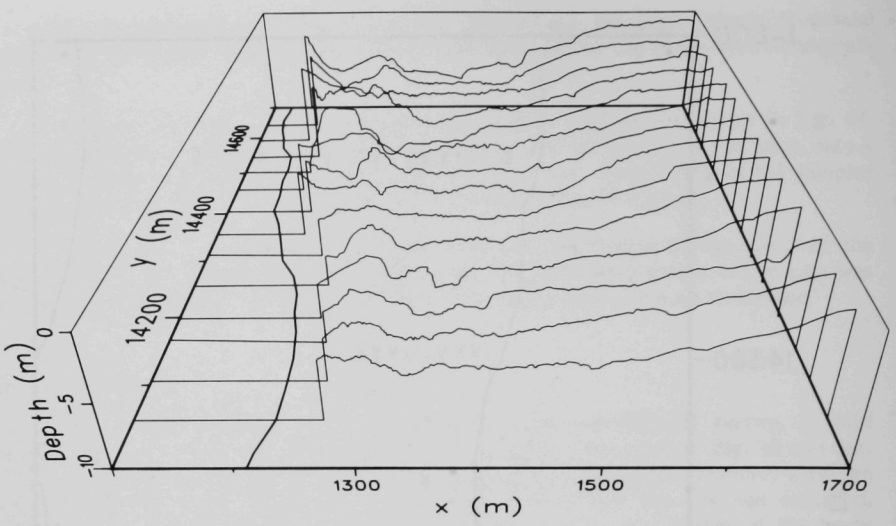

FIGURE 48 Perspective Plot of Transverse Bathymetric Transects for Survey III at the Whitney Island Disposal Site

The wavelike structure extended into the region of the disposal pile and had become somewhat less regular. The wavelength also appeared to have increased; however, because of the irregularity, it was difficult to extract a typical value. The trough-to-crest amplitude had also increased slightly to about 2 m.

In Secs. 4.2 and 4.3.1-4.3.2, little change was reported to have occurred in the areal extent of the tagged sand for the first three surveys; however, Fig. 52 shows that a portion of the tagged sand had migrated about 0.4 km downstream since Survey III. Detailed dyed sand sampling results are shown in Sec. B.2 of App. B. The cause of the downstream migration was almost certainly the flooding during November and December of 1982. As seen in Fig. 37, the flow at Lock and Dam 22 peaked at about 8000 m^3/s on December 4, 1982. Flow during the peak flooding period was nearly four times the typical flows that had occurred from the time of dredging through Survey III.

The total area enclosed by the three-dyed-sand-grain contour had increased by about 22% from Survey III to Survey IV and about 44% since Survey I. After the December flood, the area of tagged sand had separated into two distinct regions. The area of the region that remained near the original disposal site was about half that of the original region, and the area of the region about 0.4 km downstream was about equal to that of the original region. For the first three surveys, the general location of samples with the highest number of dyed sand grains had been near the transect at y = 14,100 m; after the December 1982 flood, the number of dyed grains in that area was below the three-dyed-sand-grain contour limit. The number of dyed sand grains per sampling

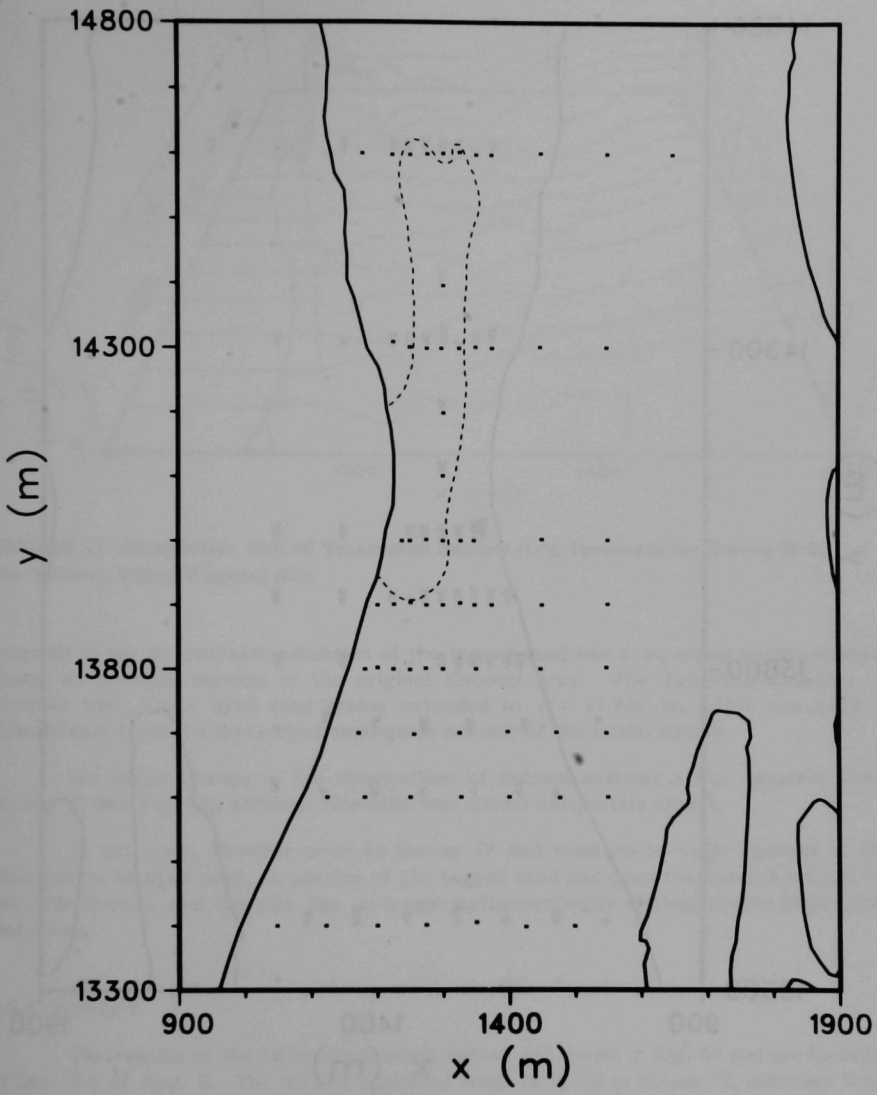

FIGURE 49 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey III at the Whitney Island Disposal Site

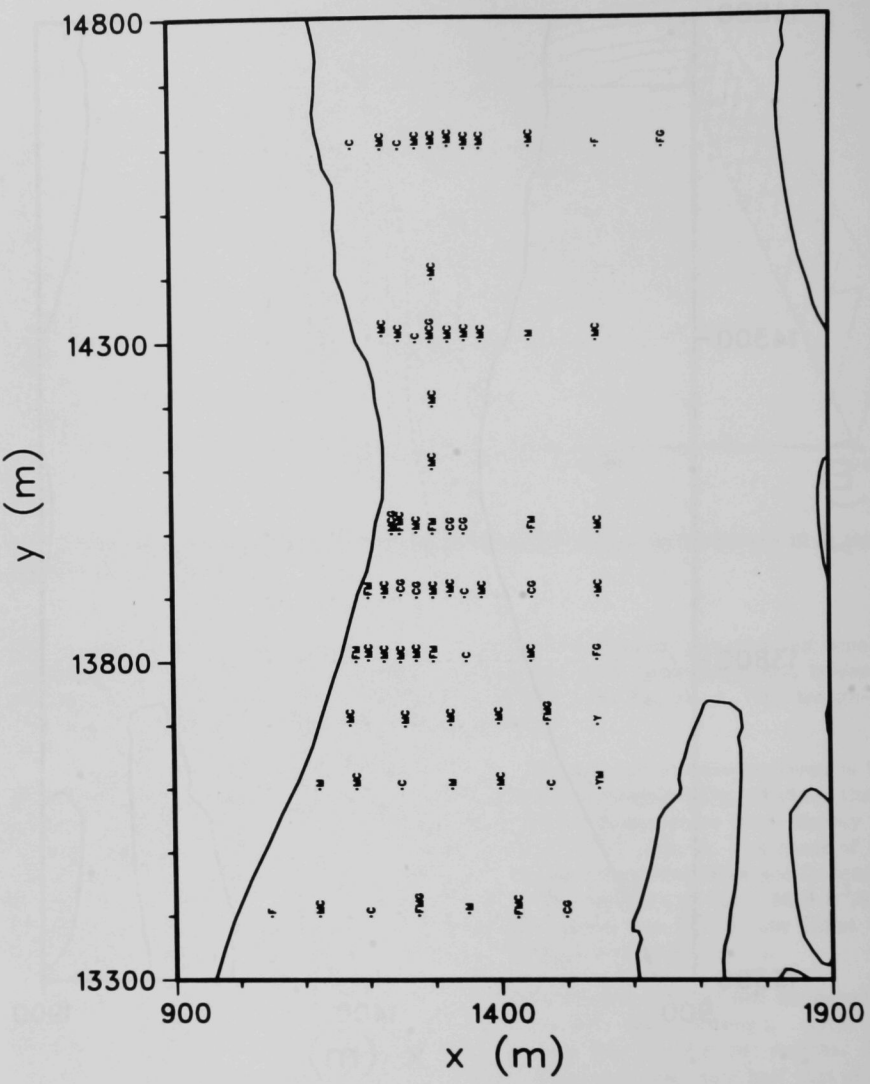

FIGURE 50 Approximate Classification of Bottom Sediments at Sampling Locations for Survey III at the Whitney Island Disposal Site

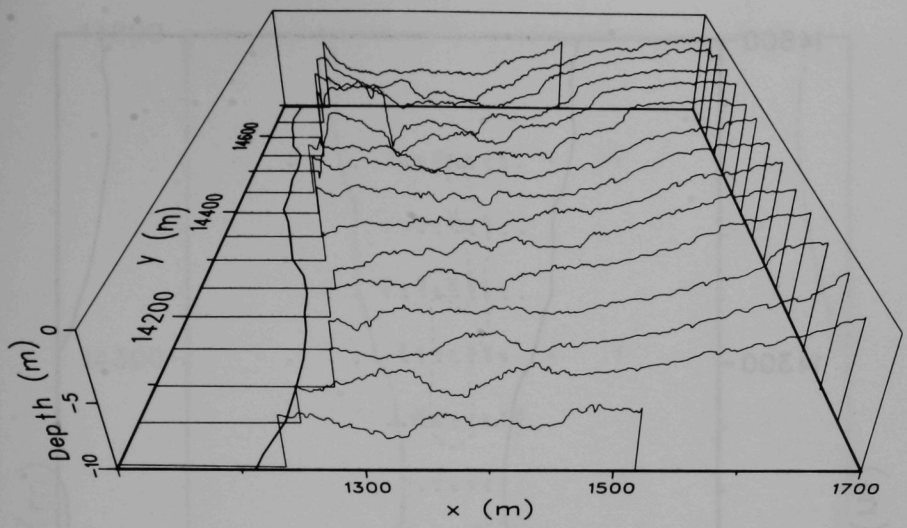

FIGURE 51 Perspective Plot of Transverse Bathymetric Transects for Survey IV at the Whitney Island Disposal Site

location in the downstream extension of the tagged sand was comparable to the numbers found on previous surveys in the original disposal area. The downstream extent of samples with single dyed sand grains extended to y = 12,800 m, which was 1100 m downstream from the three-dyed-sand-grain contour of the initial survey.

No major change in the composition of bottom sediments was apparent since Survey III (see Fig. 53), although fine sand was almost completely absent.

In summary, flooding prior to Survey IV had resulted in major changes in the distribution of dyed sand. A portion of the tagged sand had been transported almost 0.4 km downstream, and the pile was no longer bathymetrically distinguishable from other bed forms.

4.3.4 Survey V

The results of the fifth bathymetric survey are shown in Fig. 54 and are included in Sec. B.1 of App. B. The bottom appeared much as it did in Survey IV, although some small changes had occurred. The average bottom elevation in the region where the disposal pile had been located was about 0.5 m below what it had been before the disposal operation. Three additional north-south transects were added just east of the original five north-south transects. These new transects were out of the main channel of the river in shallower water and did not exhibit the same distinct wavelike features as the other longitudinal transects.

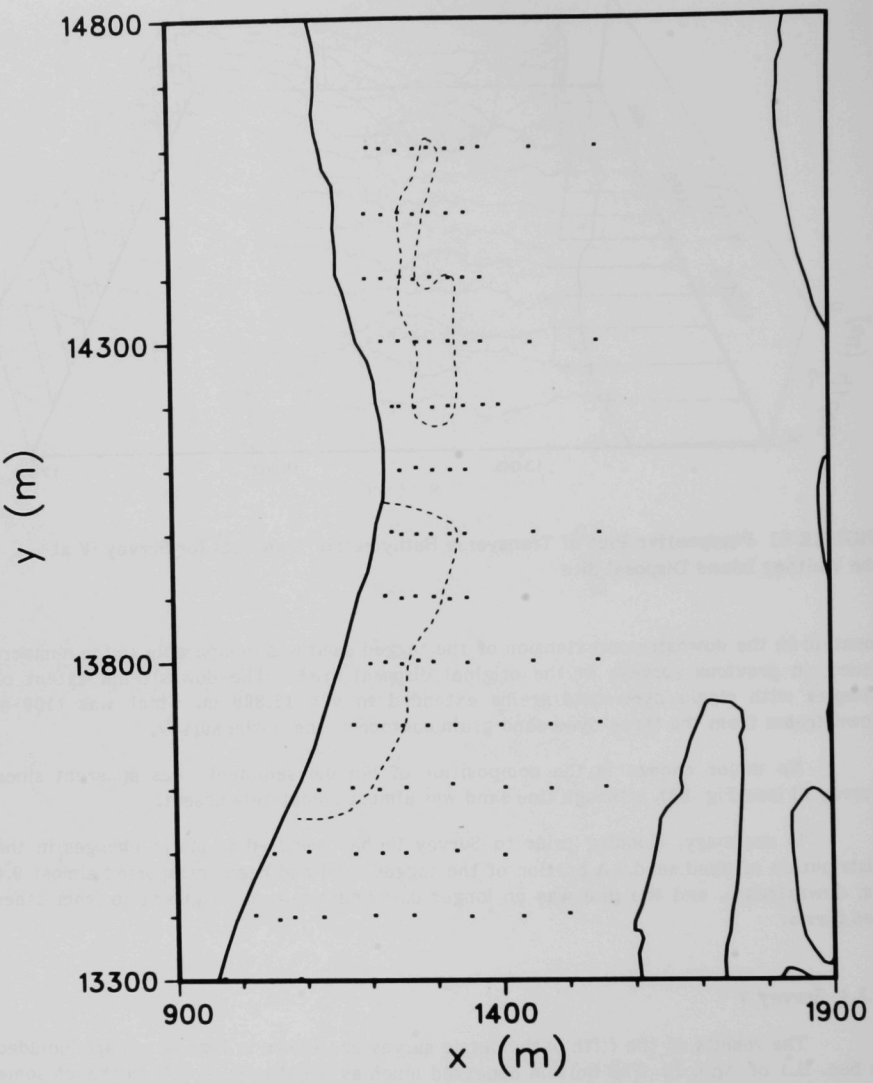

FIGURE 52 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey IV at the Whitney Island Site

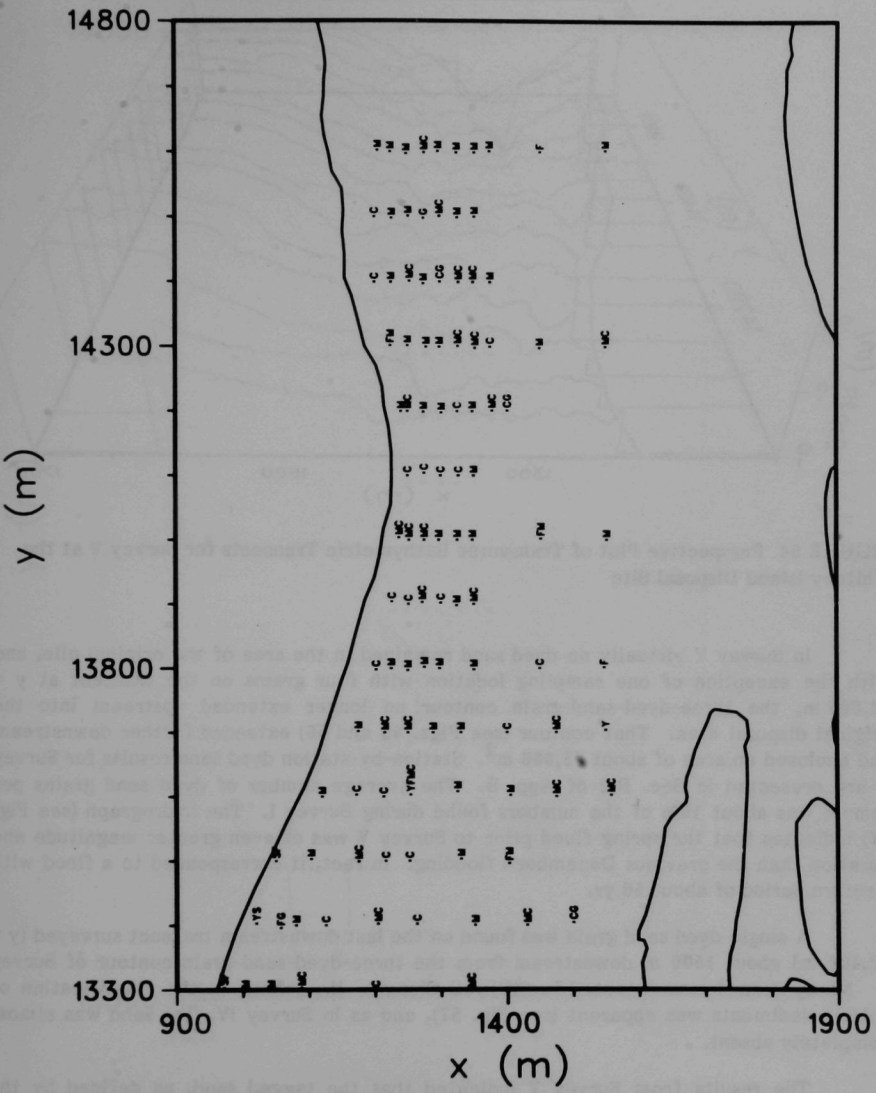

FIGURE 53 Approximate Classification of Bottom Sediments at Sampling Locations for Survey IV at the Whitney Island Disposal Site

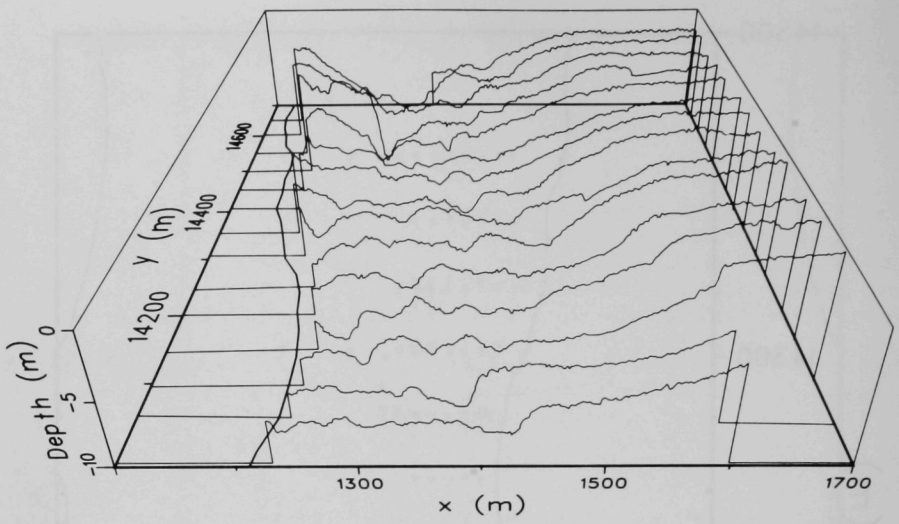

FIGURE 54 Perspective Plot of Transverse Bathymetric Transects for Survey V at the Whitney Island Disposal Site

In Survey V virtually no dyed sand remained in the area of the original pile, and with the exception of one sampling location with four grains on the transect at y = 14,000 m, the three-dyed-sand-grain contour no longer extended upstream into the original disposal area. That contour (see Figs. 55 and 56) extended farther downstream and enclosed an area of about 75,000 m^2. Station-by-station dyed sand results for Survey V are presented in Sec. B.2 of App. B. The average number of dyed sand grains per sample was about 10% of the numbers found during Survey I. The hydrograph (see Fig. 37) indicates that the spring flood prior to Survey V was of even greater magnitude and duration than the previous December's flooding. In fact, it corresponded to a flood with a return period of about 50 yr.

A single dyed sand grain was found on the last downstream transect surveyed (y = 12,400 m) about 1500 m downstream from the three-dyed-sand-grain contour of Survey I. No dyed sand was detected in Stillwell Slough. No change in the classification of bottom sediments was apparent (see Fig. 57), and as in Survey IV, fine sand was almost completely absent.

The results from Survey V indicated that the tagged sand, as defined by the three-dyed-sand-grain contour, had migrated about 0.8 km downstream from its location just after disposal and almost 0.5 km from its location in the previous survey. The number of dyed sand grains per sample within the contour had been reduced by about an order of magnitude. Virtually no dyed sand remained in the original disposal area. The downstream migration was probably a result of the unusually high spring floods of 1983.

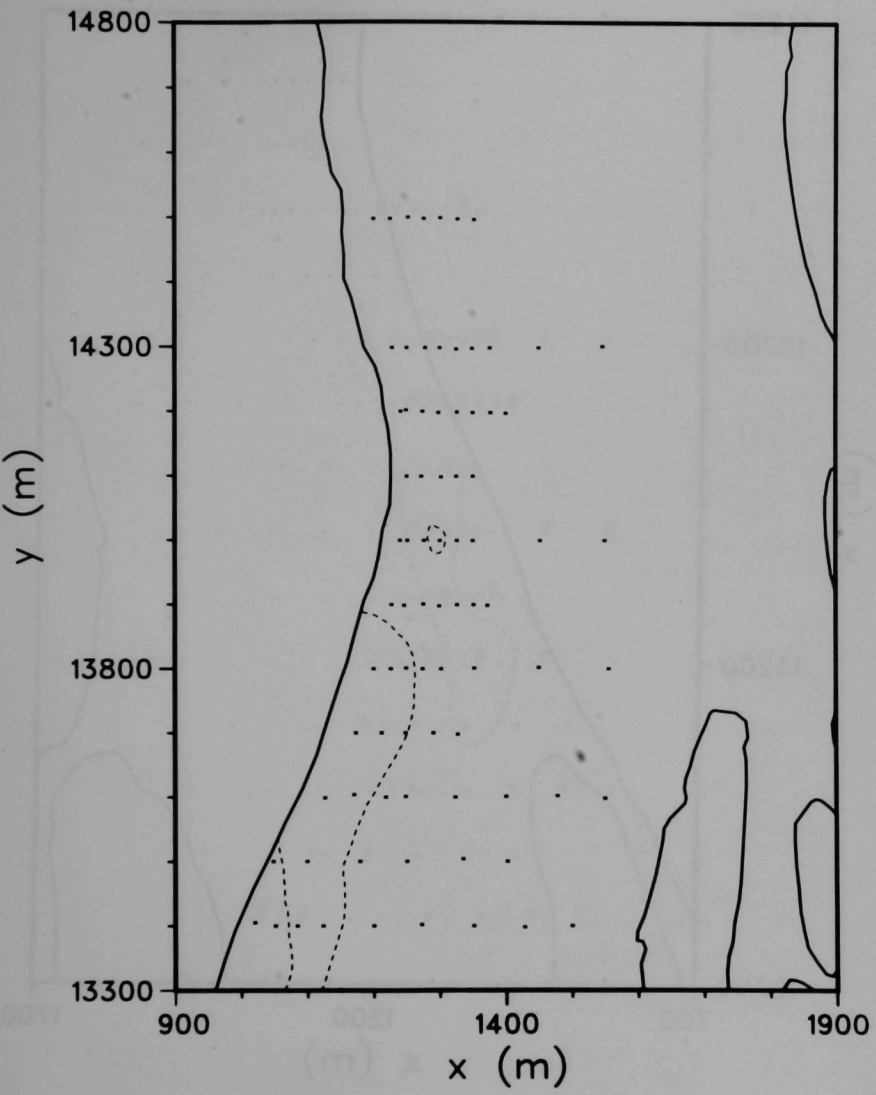

FIGURE 55 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey V at the Whitney Island Disposal Site

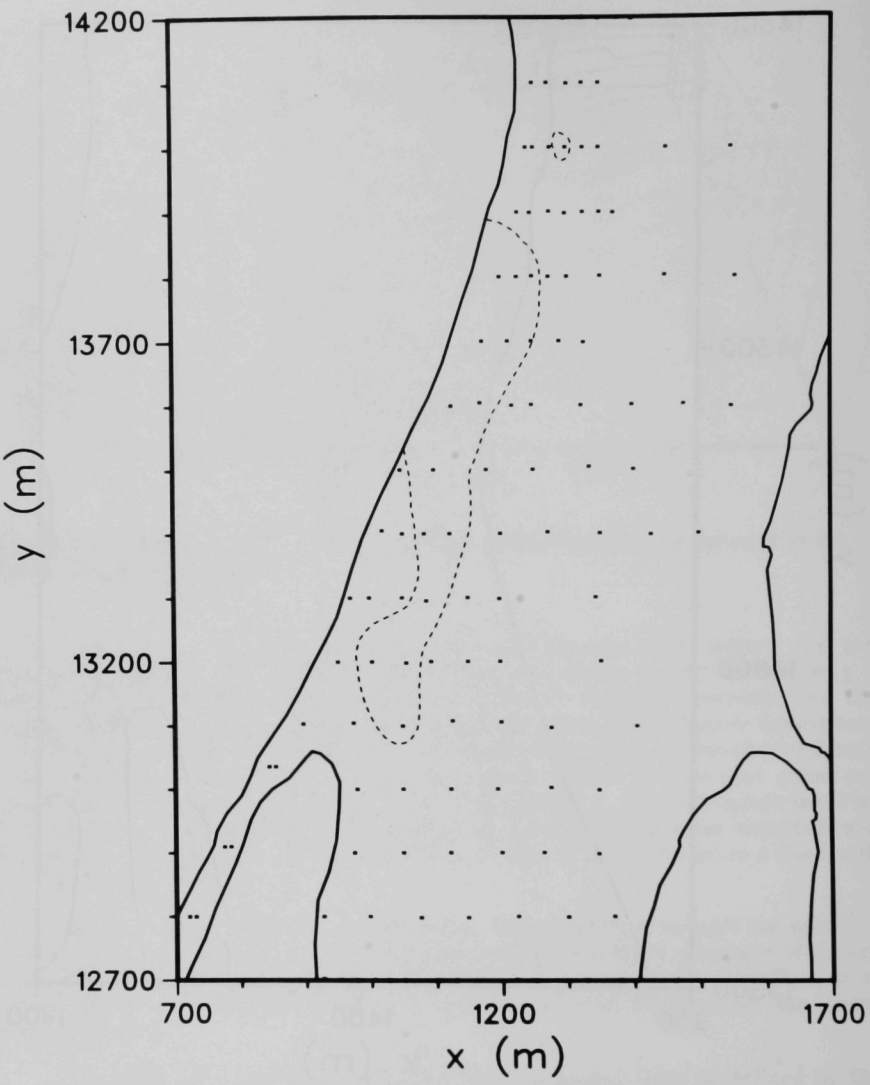

FIGURE 56 Sampling Locations and the Three-Dyed-Sand-Grain Contour for Survey V Downstream of the Whitney Island Disposal Site

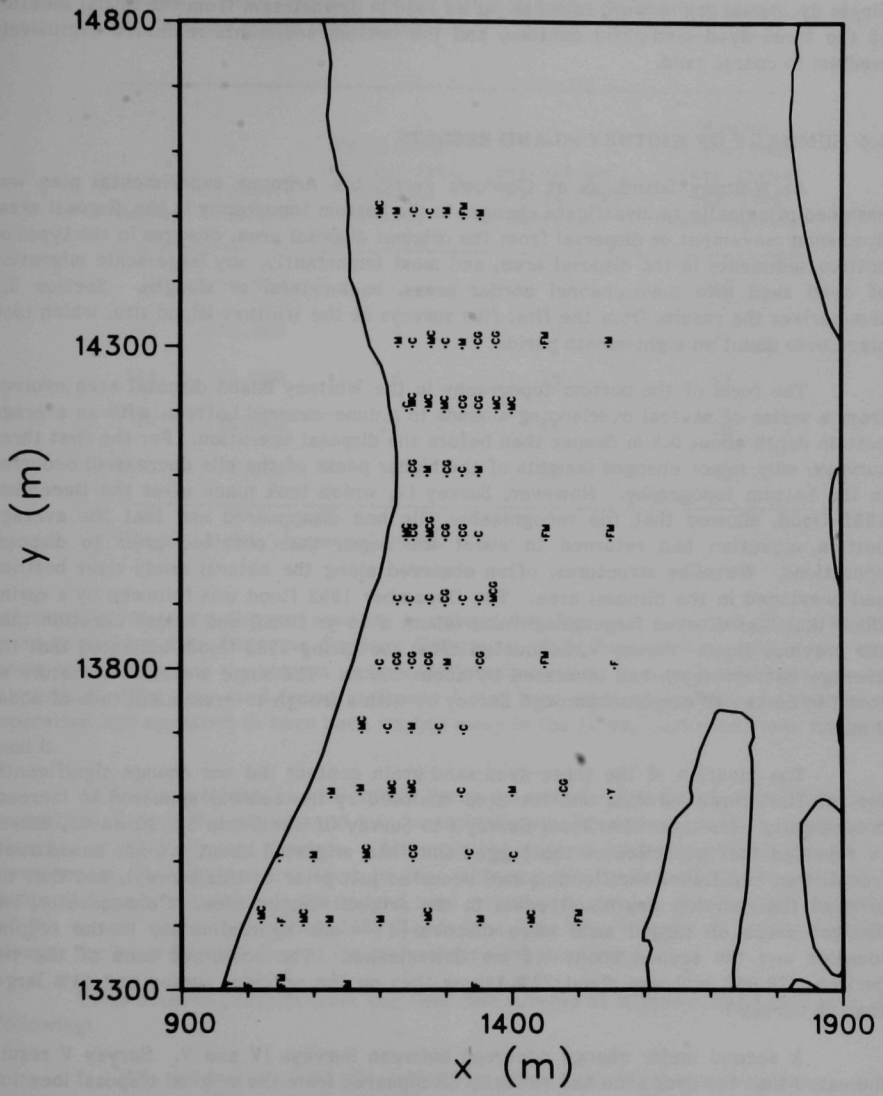

FIGURE 57 Approximate Classification of Bottom Sediments at Sampling Locations for Survey V at the Whitney Island Disposal Site

Single dyed sand grains were found as far as 1500 m downstream from the initial location of the three-dyed-sand-grain contour, and the bottom sediments remained exclusively medium to coarse sand.

4.4 SUMMARY OF WHITNEY ISLAND RESULTS

At Whitney Island, as at Gordon's Ferry, the Argonne experimental plan was designed principally to investigate changes in the bottom topography in the disposal area, dyed sand movement or dispersal from the original disposal area, changes in the types of bottom sediments in the disposal area, and most importantly, any large-scale migration of dyed sand into main-channel border areas, backwaters, or sloughs. Section 4.4 summarizes the results from the first five surveys at the Whitney Island site, which took place over about an eight-month period.

The form of the bottom topography in the Whitney Island disposal area evolved from a series of several overlapping mounds to a dune-covered bottom, with an average bottom depth about 0.5 m deeper than before the disposal operation. For the first three surveys, only minor changes (heights of the higher peaks of the pile decreased) occurred in the bottom topography. However, Survey IV, which took place after the December 1982 flood, showed that the recognizable pile had disappeared and that the average bottom elevation had returned to about the depth that obtained prior to disposal operations. Wavelike structures, often observed along the natural sandy river bottom, had developed in the disposal area. The December 1982 flood was followed by a spring flood that was of even larger magnitude (about a 50-yr flood) and longer duration than the previous flood. Survey V, conducted after the spring 1983 flood, indicated that the average bottom depth had increased by about 0.5 m. The same wavelike structure as found in Survey IV persisted through Survey V, with a trough-to-crest amplitude of about 2 m.

The location of the three-dyed-sand-grain contour did not change significantly for the first three surveys, and the area enclosed by the contour appeared to increase only slightly (less than 20%) from Survey I to Survey III (see Table 5). However, Survey IV revealed that a portion of the tagged sand had migrated about 0.4 km downstream (recall that the December flooding had occurred just prior to this survey), and that the area of that portion was about equal to the original tagged area. Consequently, two distinct areas of tagged sand were discovered -- one approximately in the original location and the second about 0.4 km downstream. The combined area of the two portions (78,000 m^2) was about 22% larger than on the previous survey and 44% larger than on Survey I.

A second major change occurred between Surveys IV and V. Survey V results indicated that the dyed sand had virtually disappeared from the original disposal location, the area enclosed by the three-dyed-sand-grain contour (75,000 m^2) was about 40% larger than the original area and was located about 0.8 km downstream, and the number of dyed sand grains per sample within the three-dyed-sand-grain contour was reduced to about 10% of that found on the initial survey.

The fine sand found in the bottom sediments during Survey I disappeared by Survey II, and no significant changes in grain size were noted after that. Sediment

TABLE 5 Area Enclosed by the Three-Dyed-Sand-Grain Contour at the Whitney Island Disposal Site

Survey	Area (m^2)	Percentage Change from Previous Survey	Percentage Change from Survey I	Number of Stations within Three-Dyed-Sand-Grain Contour
I	54,000			26
II	59,000	9	9	12
III	64,000	8	19	13
IV	78,000[a]	22	44	29
V	75,000	-4	39	15

[a]Total of two separate areas.

characteristics in the disposal area are summarized in Fig. 58 in a manner similar to that used to present data from the Gordon's Ferry site. Only fine, medium, and coarse sand were considered, and the bottom was predominately medium to coarse sand for Surveys II through V. The fine sand found in Survey I may have been an artifact of the disposal operation and appeared to have been washed away in the 10-day period between Surveys I and II.

At Whitney Island, as at Gordon's Ferry, no evidence was found of any significant migration of tagged dredged sand into biologically sensitive areas, such as backwaters, sloughs, or main-channel borders. Although the tagged sand migrated about 0.8 km downstream, it remained confined to the thalweg. No dyed sand was ever found in Stillwell Slough, even though the tagged sand moved very close to the upstream entrance of the slough during the spring 1983 floods (see Fig. 56). Instead of moving into the slough, the tagged sand followed the main channel of the river.

To summarize, results from the first five surveys at Whitney Island indicated the following:

1. The original disposal pile, which was quite distinct topographically, disappeared among natural bed forms after a flooding event. Following a second and more severe flood, the average bottom elevation decreased to about 0.5 m below that prior to disposal.

2. The tagged sand, as defined by the three-dyed-sand-grain contour, migrated about 0.8 km downstream after a major flooding event

(50-yr return period), with virtually no dyed sand remaining in the original disposal area.

3. The bottom sediments in the original disposal area remained medium to coarse sand.

4. No evidence of tagged dredged sand was found in backwaters, sloughs, or main-channel border areas.

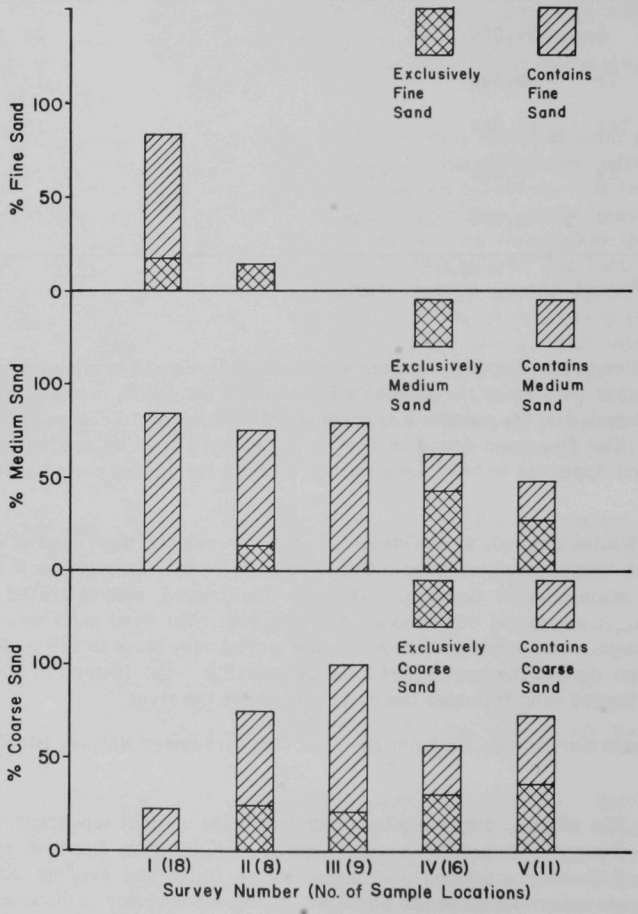

FIGURE 58 Bottom Sediment Classification in the Disposal Area at the Whitney Island Site for Each Survey

5 SUMMARY AND CONCLUSIONS

Argonne has conducted two large-scale field experiments on the Upper Mississippi River, the initial phases of which are presented in this report. The experiments were designed to measure the movement of dredged sand, which has been tagged with dyed sand and returned to a deeper reach of the main river channel downstream of the dredging site. The experimental site at Gordon's Ferry was surveyed seven times within a period of 588 days after disposal. The Whitney Island site was surveyed five times within a period of 249 days after disposal. The surveys consisted of bathymetric measurements and bottom sample observations to determine the downstream distribution of the tagged dredged sand. The experiments documented here have not been completed; that is, the field work at each site has continued beyond the surveys reported here. However, some conclusions can be drawn on the basis of the data presented in this report. And, none of the more recent data from these two sites would appear to call into question any of the conclusions so drawn.

5.1 FEASIBILITY OF CONDUCTING THALWEG DISPOSAL EXPERIMENTS

The experiments at the two sites demonstrated the feasibility of conducting large-scale field experiments with tagged dredged sand. No significant logistical or operational problems arose with regard to dyeing large amounts of river sand and injecting it into the dredged sand stream prior to disposal. Matching the size distributions of the dyed sand and dredged sand is not considered a serious problem.

Sampling for and detecting dyed sand in the surficial bottom sediments of the river was accomplished with relative ease. The inherent flexibility of the sampling technique and procedures was proven, when after initial surveys at the Gordon's Ferry site, it was found necessary to provide higher resolution sampling in the vicinity of the disposal pile. The precision navigation and onboard plotting systems allowed efficient and reliable repetitive sampling. No significant interference occurred with dyed sand detection caused by background fluorescent materials.

The combination of bathymetric measurements in the vicinity of the original disposal pile and sampling for dyed sand proved particularly valuable in understanding changes at each experimental site. While bathymetric data on transects across the pile could not be collected with sufficient precision to allow exact study of changes along a particular transect from one survey to another, the overall picture of the disposal pile provided by the bathymetric data was important. As the disposal pile lost its identity among natural bed forms, the dyed sand data became particularly useful for identifying the location of the dredged sand.

In summary, the general experimental approach proved not only feasible but also flexible with regard to changing conditions in the field. It provided a relatively detailed view of the distribution of dyed sand in the surficial sediments in and around the disposal pile.

5.2 EXPERIMENTAL RESULTS

Summaries of the site-specific results are given for each experiment in Secs. 3.4 and 4.4. Section 5.2 discusses more general results that are applicable to both sites. The general pattern of dredged sand behavior after disposal was the same at both sites. Immediately after disposal, the dredged sand seemed to remain in its original configuration, that is, in a discrete pile or piles. Dyed sand found downstream of the disposal site in the initial survey seems most likely to have been transported there as a result of the above-water disposal operation. Little downstream movement of tagged dredged sand was detected until periods of flooding. In response to these periods of flooding, the tagged sand was apparently mobilized along with other bed material and moved downstream in the main channel. The bathymetric identity of the pile seems to have disappeared after such major discharge events, with the tagged sand having apparently been incorporated into bed forms in the main-channel area.

In the Gordon's Ferry experiment, surficial samples indicated that the dyed sand had moved downstream as a continuous extension of the original disposal pile. At the Whitney Island site, the evidence from surficial sediment samples showed only small amounts of dyed sand remaining at the original disposal site. Coupled with the fact that the average bottom depth was 0.5 m deeper than before disposal, this result suggests that after flooding the tagged sand moved downstream away from the original disposal site.

Extensive sampling downstream of the disposal area at both sites indicated no evidence of tagged dredged sand being transported out of the main channel. Sampling in sensitive areas (e.g., main-channel borders, backwaters, and sloughs) identified only one or two dyed sand grains on one or two sampling occasions. Thus, no evidence was found of coherent movement of dredged sand directly into such sensitive areas, and no evidence supported earlier speculation that sand dispersed from the disposal area might accumulate there.

The differences in results at the two experimental sites can be attributed both to the configuration of the original disposal piles and the hydraulics at the local sites. At Gordon's Ferry, the dredged sand was placed in a discrete pile in the middle of a deep main-channel reach such that it occupied less than one-fourth of the water depth at that point. In contrast, the disposal piles at the Whitney Island site were placed in a main-channel reach that hugs the Missouri shoreline. Moreover, the average height of the piles at this site was on the order of one-half of the predisposal water depth. Of even more importance is the relative magnitudes of the floods experienced at each site. The large discharge at Gordon's Ferry in the spring of 1983 was equivalent to a flood with a return period of only 5-10 yr. On the other hand, the major flooding event at the Whitney Island site in early spring 1983 was estimated to be equivalent to a flood with a 50-yr return period. Despite these differences in geometry and hydraulics, the general behavior of the dredged sand at both sites was similar.

5.3 FUTURE ACTIVITIES

The experiments at Gordon's Ferry and Whitney Island have continued beyond the period covered here. The results of later phases of this study will be documented in a

subsequent volume of this report. Planned activities include continued monitoring of the sites through surveys of the type reported here and bottom coring at Gordon's Ferry. The coring studies will provide a three-dimensional view of the distribution of tagged sand throughout the sediments of the river bed in the vicinity of the disposal pile.

REFERENCES

1. Nanda, S.K., and R.M. Baker, *Experience in Channel Maintenance in Upper Mississippi River*, Proc. Rivers '83 Conf., sponsored by American Society of Civil Engineers, New Orleans, Oct. 1983, pp. 471-482 (1984).

2. Lagasse, P.F., et al., *Thalweg Disposal of Riverine Dredged Material*, Proc. Specialty Conf. on Dredging and Its Environmental Effects, sponsored by American Society of Civil Engineers, New York, pp. 556-576 (1976).

3. *Main Report, GREAT II: Upper Mississippi River (Guttenberg, Iowa, to Saverton, Missouri)*, Great River Environmental Action Team, U.S. Army Corps of Engineers, Rock Island District, Rock Island, Ill. (Dec. 1980).

4. *Channel Maintenance Handbook, Supplement to the GREAT II Main Report*, Great River Environmental Action Team, U.S. Army Corps of Engineers, Rock Island District, Rock Island, Ill. (Dec. 1980).

5. Van Loon, L.S., D.L. McCown, and J.D. Ditmars, *Sampling and Detection of Tagged Dredged Material*, Argonne National Laboratory Report ANL/EES-TM-169 (Jan. 1982).

APPENDIX A

GORDON'S FERRY — DETAILED DATA

APPENDIX A

GORDON'S FERRY — DETAILED DATA

The results and some of the data from seven postdisposal surveys at the Gordon's Ferry site were presented and discussed in Sec. 3. The complete sets of bathymetric data and dyed sand data from each of these surveys are given in Secs. A.1 and A.2 of this appendix.

A.1 BATHYMETRIC DATA FROM THE GORDON'S FERRY DISPOSAL SITE

The complete bathymetric data from the predisposal survey and the seven postdisposal surveys at Gordon's Ferry are presented in Figs. A.1-A.8. The approximate boat paths for each set of transects are shown in the upper left-hand quadrant of each figure. The bottom profiles for the transverse transects (approximately parallel to the x axis) are presented in sequence starting in the upper right-hand quadrant with the transect farthest upstream (northernmost) and proceeding downstream (southward). The profiles for the individual transects are plotted starting from the Iowa (west) end of each transect. The bottom profiles for the longitudinal transects (approximately parallel to the original disposal pile), when available, are then presented in sequence starting with the transect closest to the Illinois (east) shore and proceeding toward the Iowa (west) shore. The profiles for the individual transects are plotted starting from the downstream end of each transect.

A.2 DYED SAND DATA FROM THE GORDON'S FERRY DISPOSAL SITE

The locations of the bottom-sampling stations for each of the seven postdisposal surveys at Gordon's Ferry are presented in Sec. A.2. The study area was divided into four regions (a, b, c, and d) for presentation purposes as shown in Fig. A.9. Region a encompasses the original disposal area, and Region b includes the two principal entrances to Stone Slough and the nearby main-channel area. Region c covers the area downstream of the slough entrances, and Region d covers the upstream portion of Stone Slough. The sampling locations for Surveys I-VII are shown in Figs. A.10-A.37. The number of individual dyed sand grains, if any, observed in the photographs of the surface of the 23 cm × 23 cm sample tray illuminated by ultraviolet light is given adjacent to each sampling location. The details of the sampling and photographing procedure and the statistical significance of the number of dyed sand grains observed in any one sample were discussed in Sec. 2. In particular, recall that the camera exposure times were changed from 0.5 s and 2 s to 2 s, 7 s, and 12 s with Survey IV and thereafter.

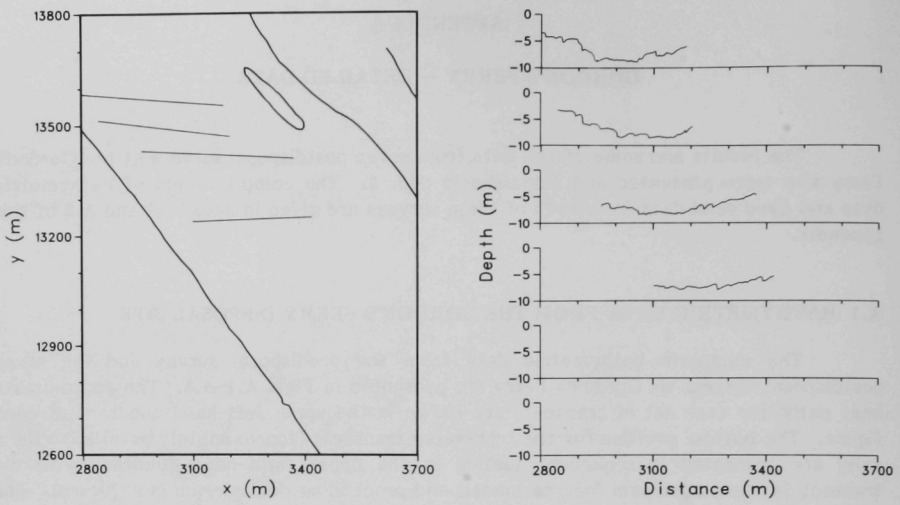

FIGURE A.1 Bathymetric Transects and Transverse Bottom Profiles for the Predisposal Survey at Gordon's Ferry on October 26, 1981

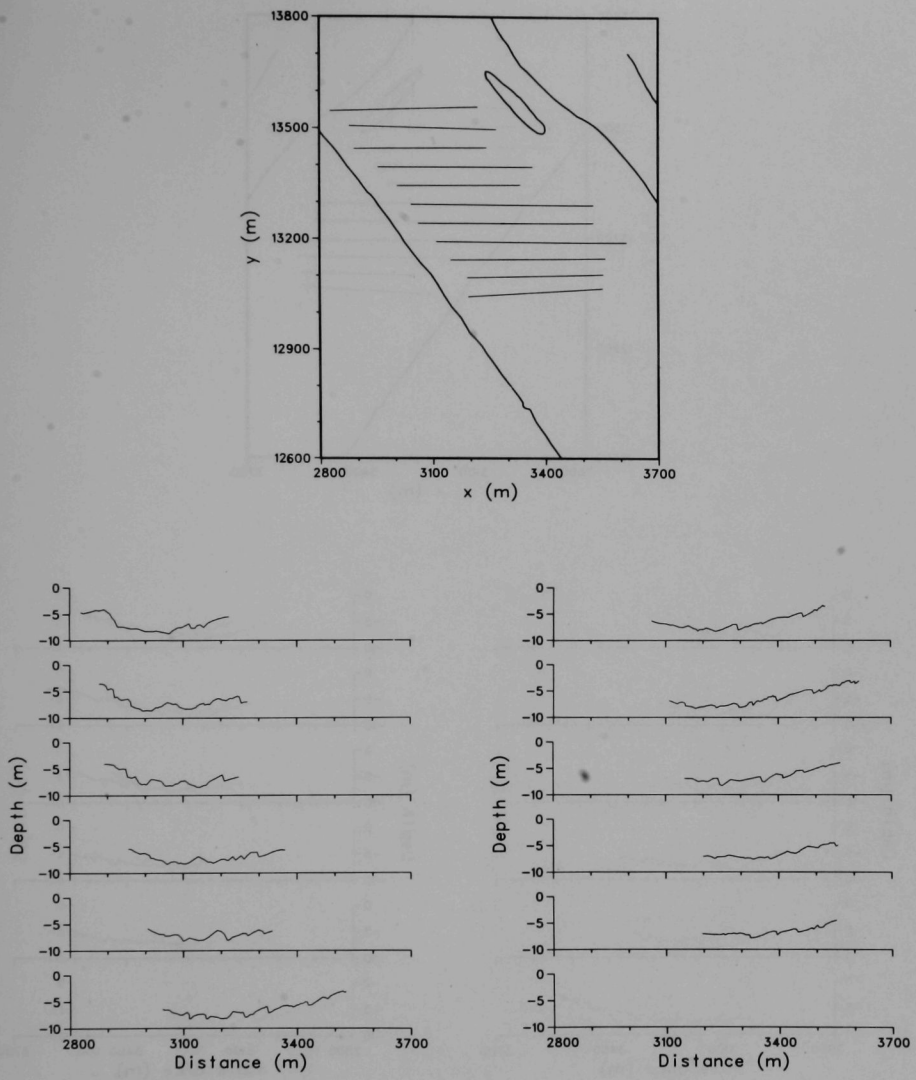

FIGURE A.2 Bathymetric Transects and Transverse Bottom Profiles for Survey I at Gordon's Ferry on October 28, 1981

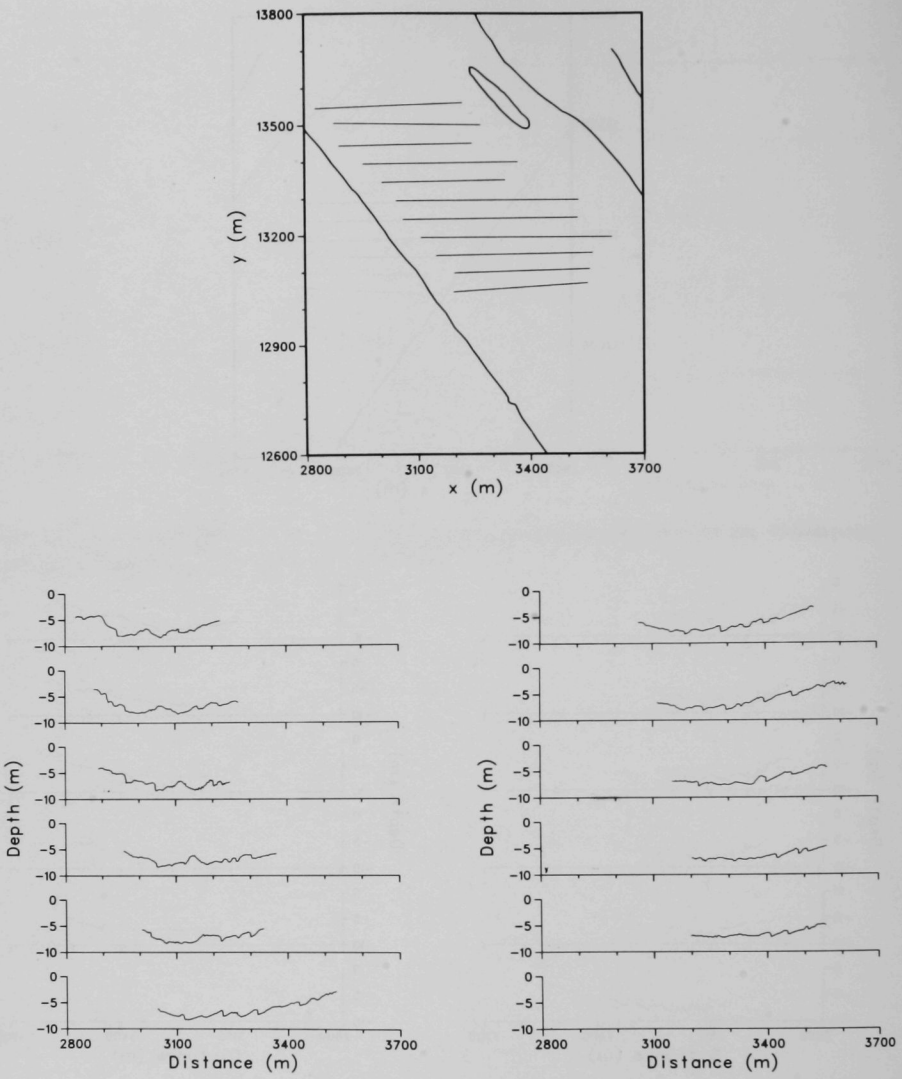

FIGURE A.3 Bathymetric Transects and Transverse Bottom Profiles for Survey II at Gordon's Ferry on November 5, 1981

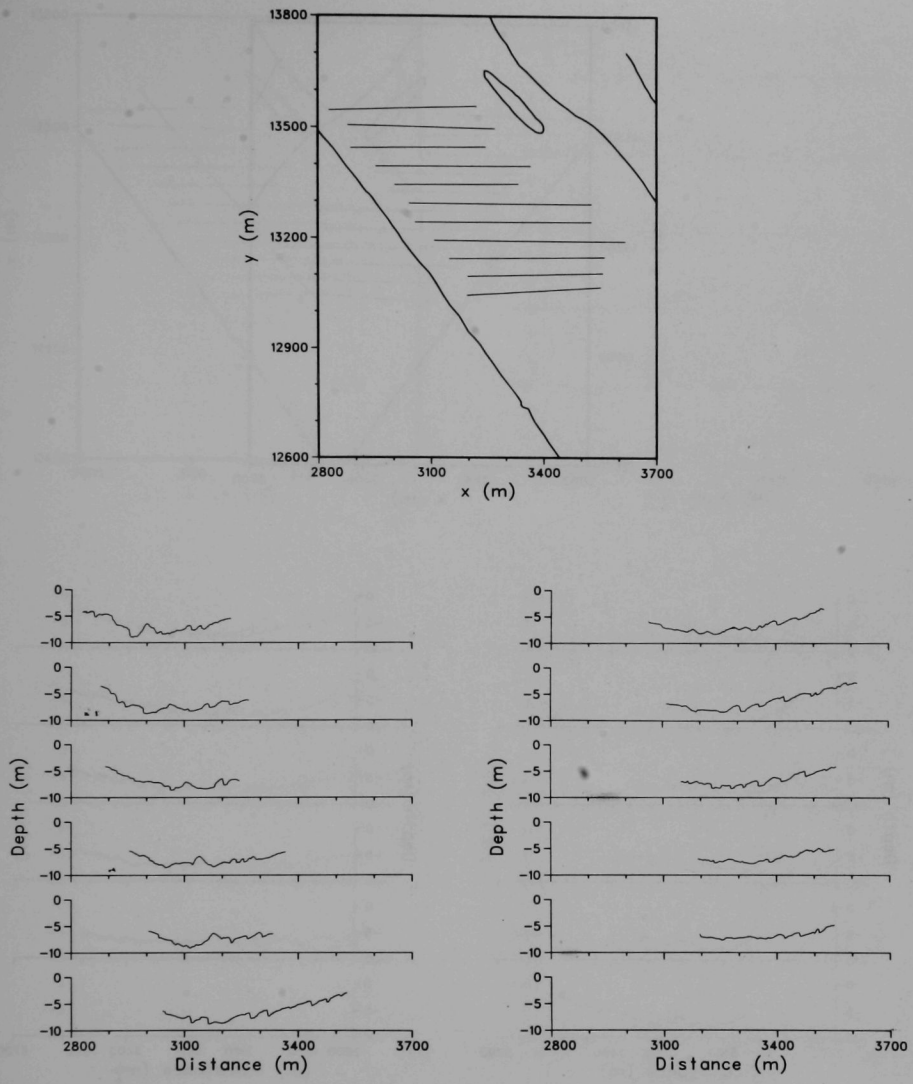

FIGURE A.4 Bathymetric Transects and Transverse Bottom Profiles for Survey III at Gordon's Ferry on December 2, 1981

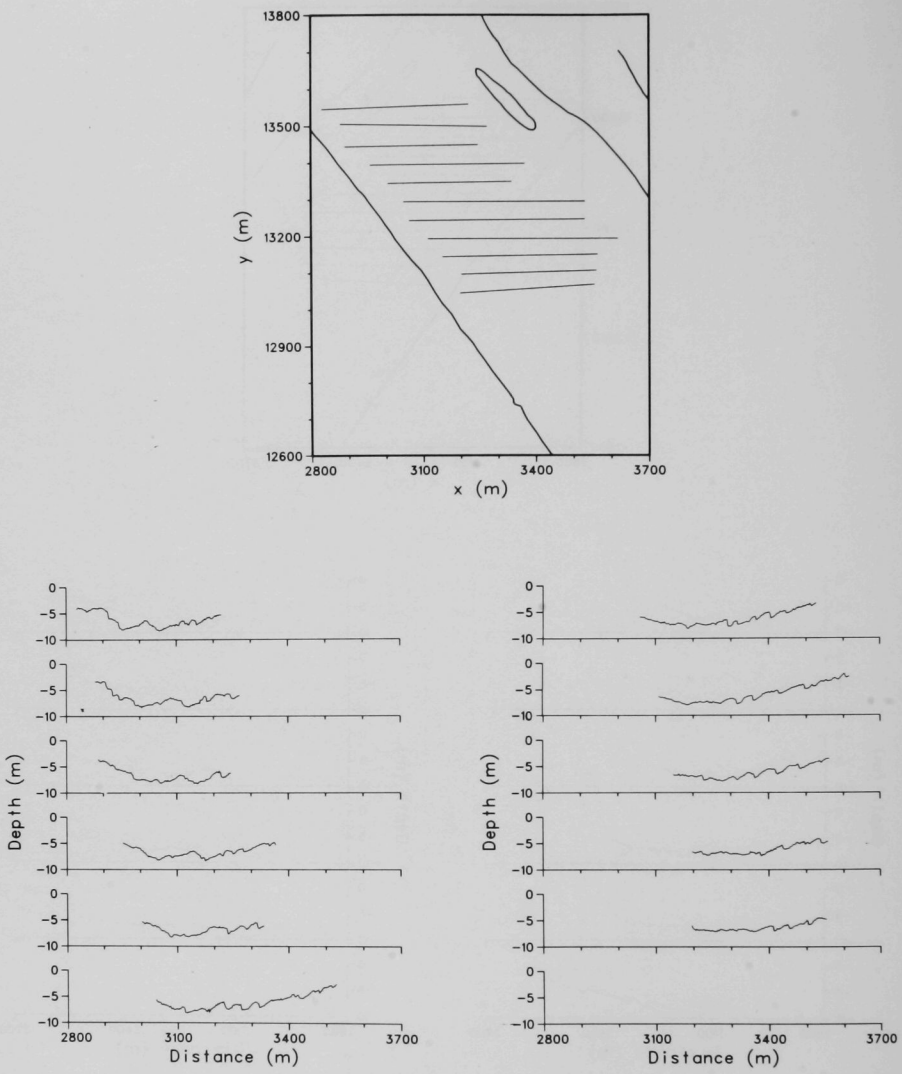

FIGURE A.5 Bathymetric Transects and Transverse Bottom Profiles for Survey IV at Gordon's Ferry on March 30, 1981

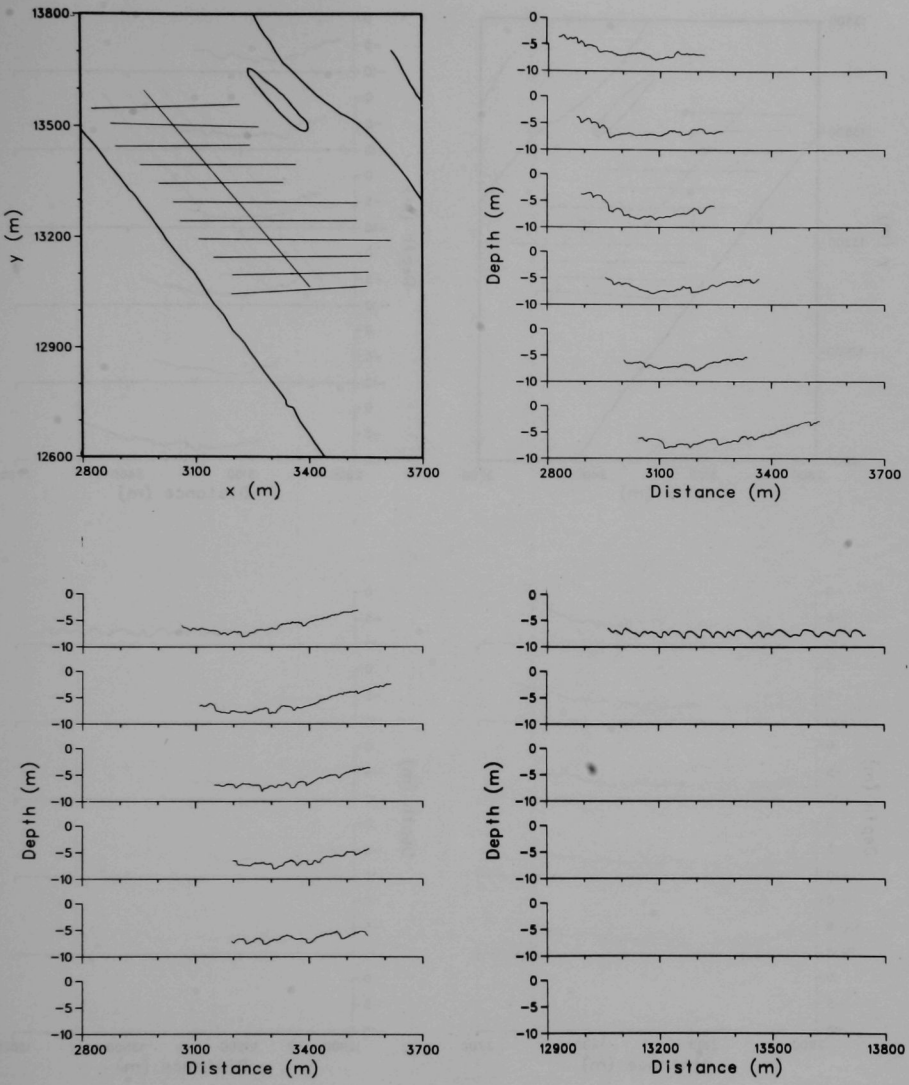

FIGURE A.6 Bathymetric Transects and Transverse and Longitudinal Bottom Profiles for Survey V at Gordon's Ferry on June 2, 1982

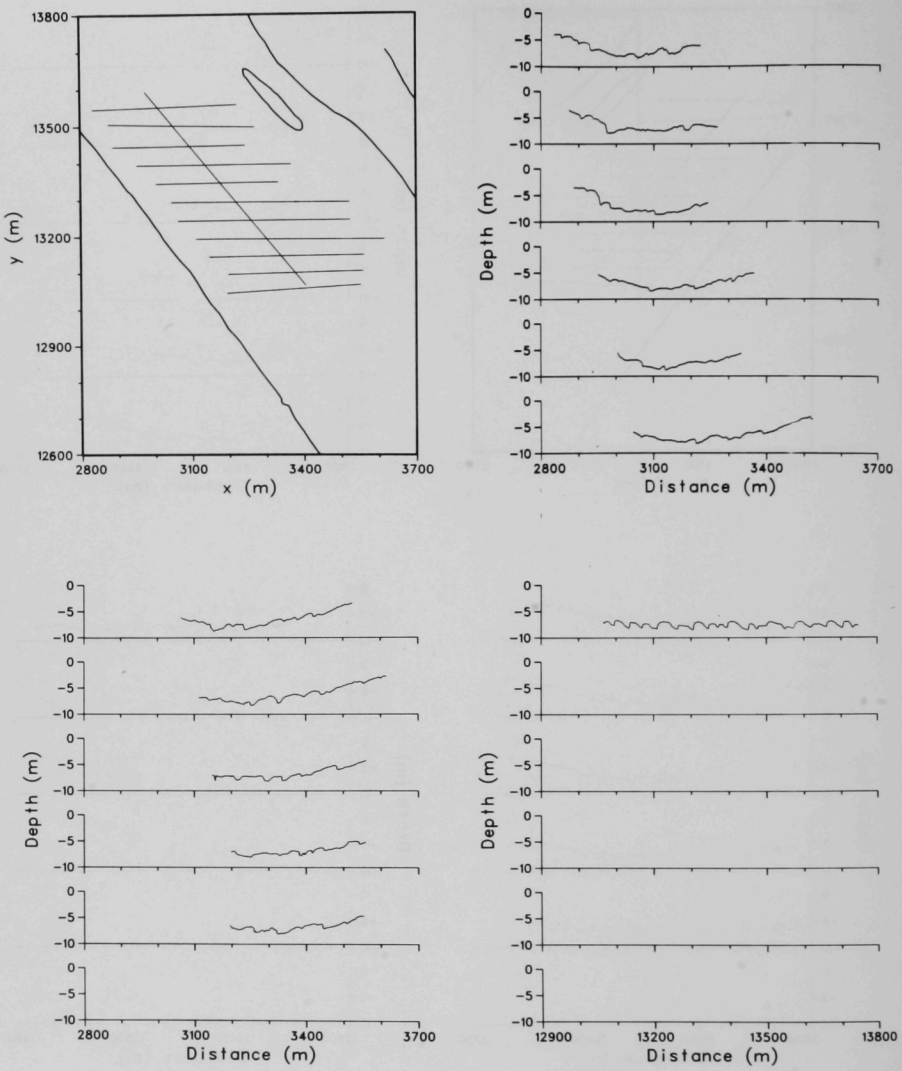

FIGURE A.7 Bathymetric Transects and Transverse and Longitudinal Bottom Profiles for Survey VI at Gordon's Ferry on October 12, 1982

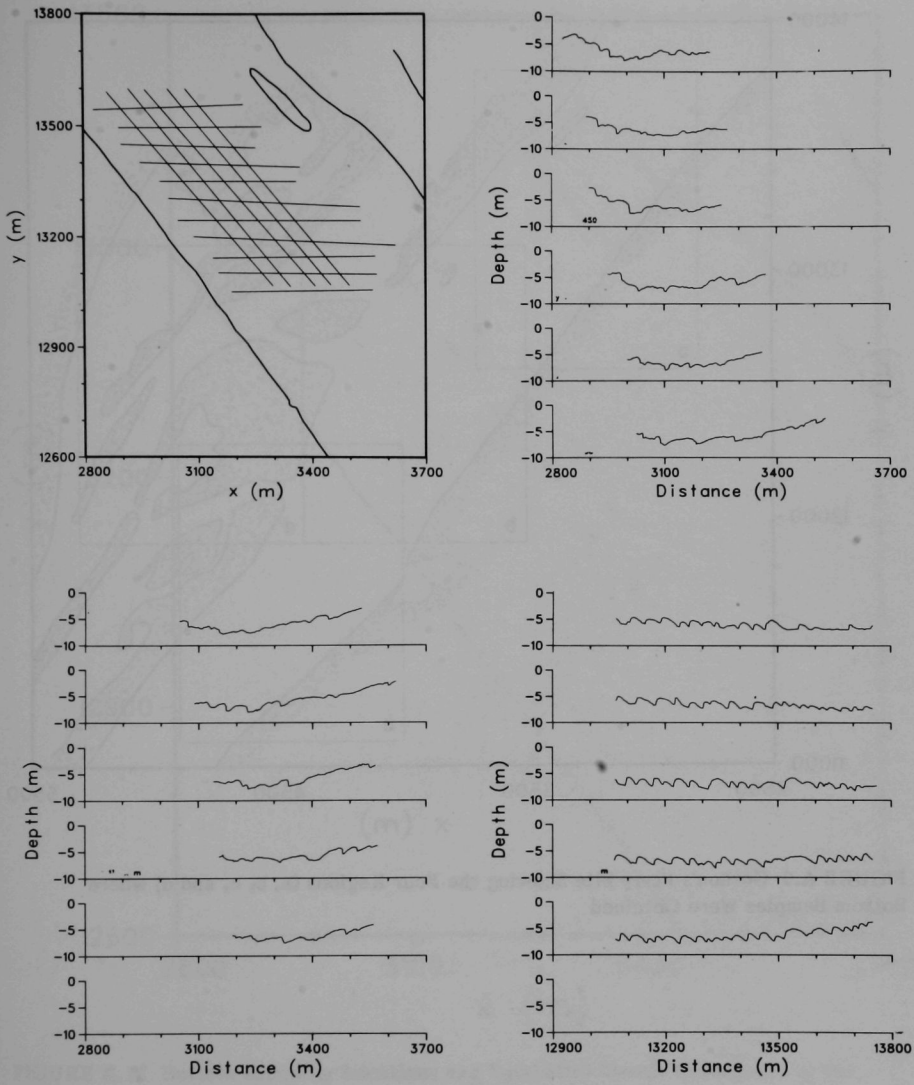

FIGURE A.8 Bathymetric Transects and Transverse and Longitudinal Bottom Profiles for Survey VII at Gordon's Ferry on June 7, 1983

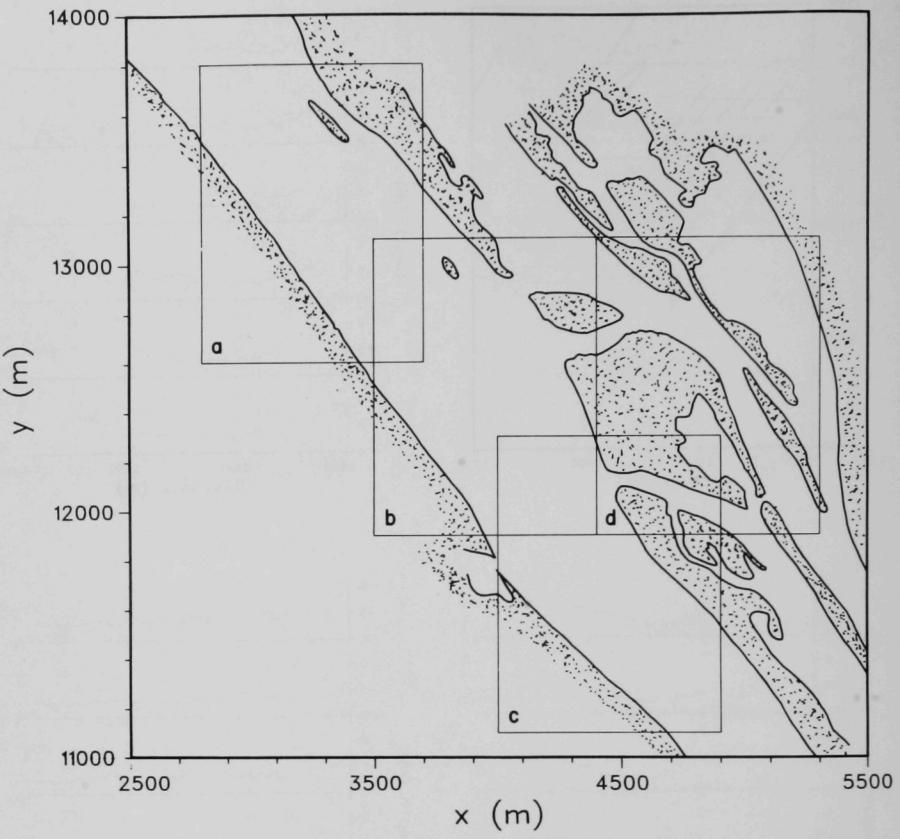

FIGURE A.9 Gordon's Ferry Site Showing the Four Regions (a, b, c, and d) where Bottom Samples Were Obtained

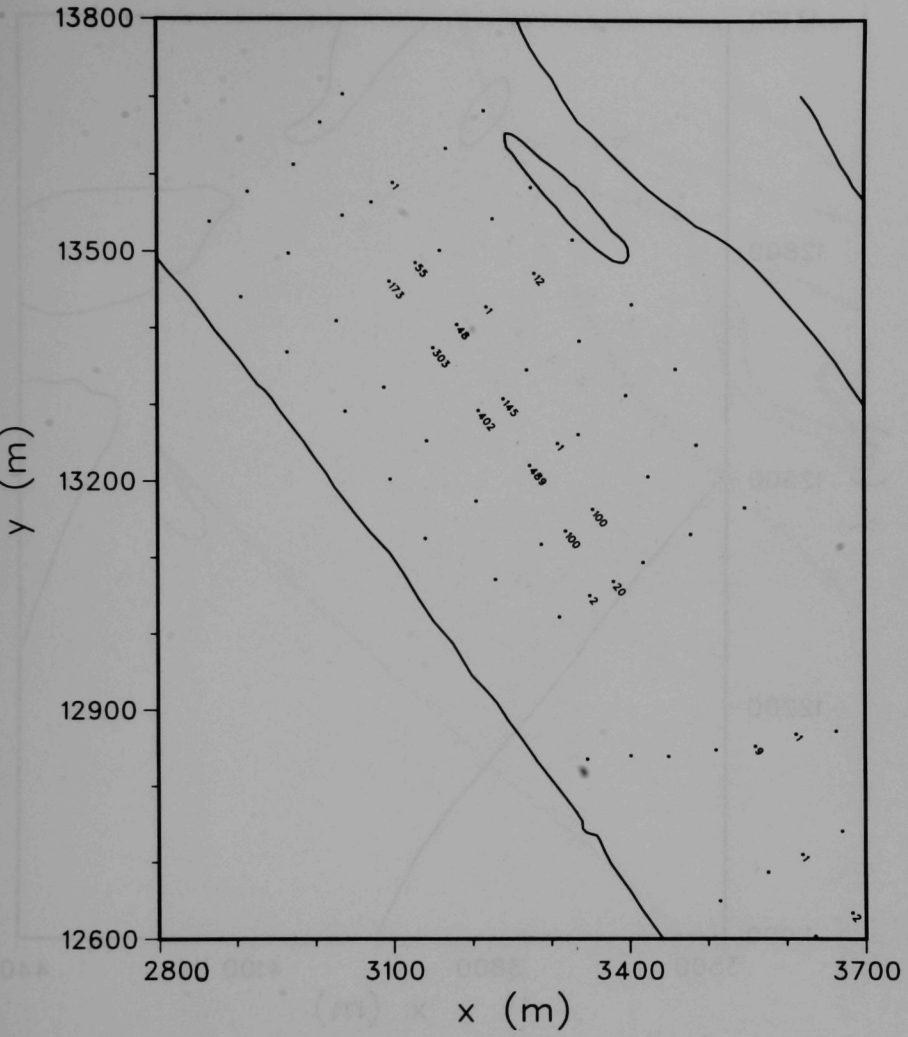

FIGURE A.10 Bottom Sampling Locations and Dyed Sand Counts in Region a of the Gordon's Ferry Site for Survey I

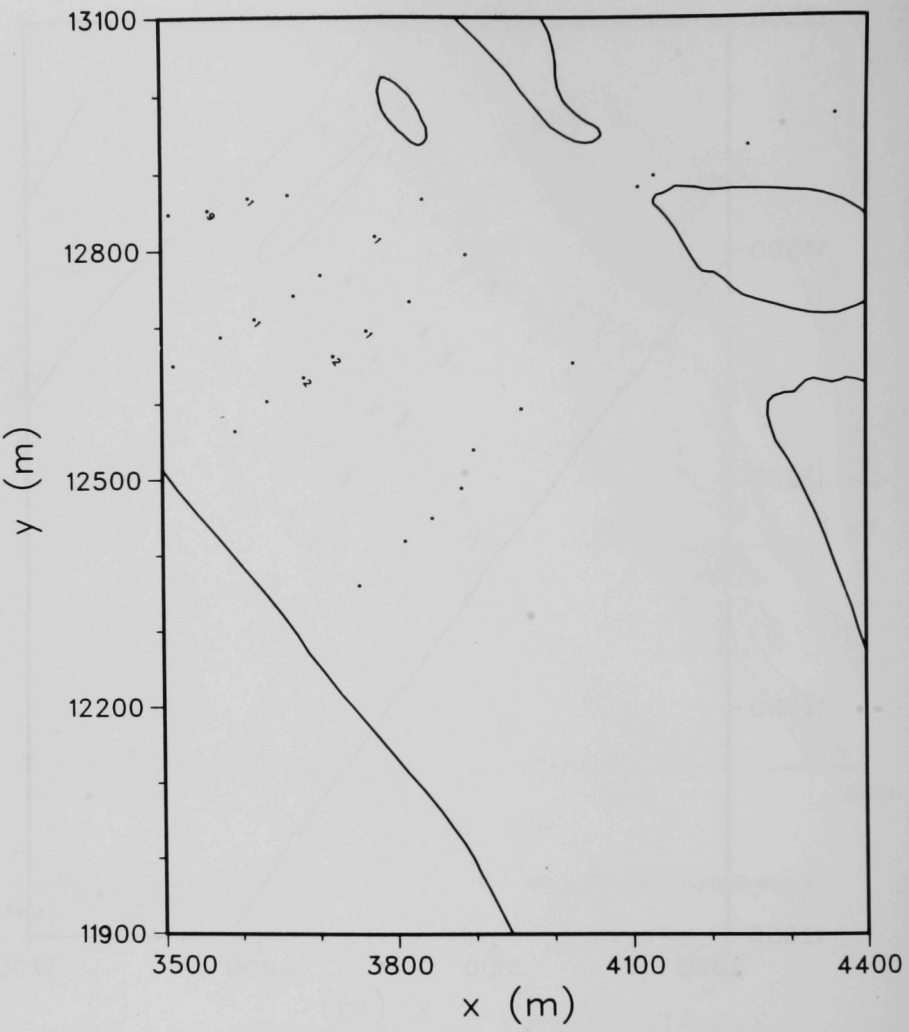

FIGURE A.11 Bottom Sampling Locations and Dyed Sand Counts in Region b of the Gordon's Ferry Site for Survey I

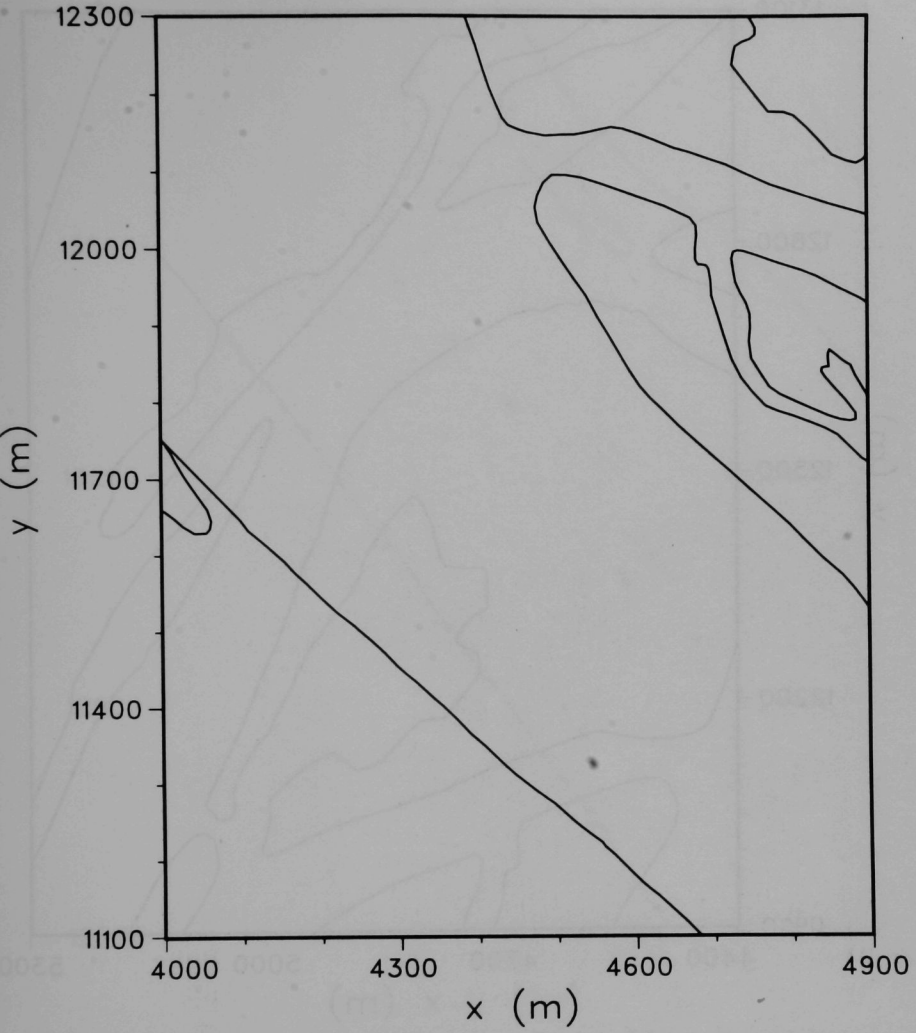

FIGURE A.12 Bottom Sampling Locations and Dyed Sand Counts in Region c of the Gordon's Ferry Site for Survey I

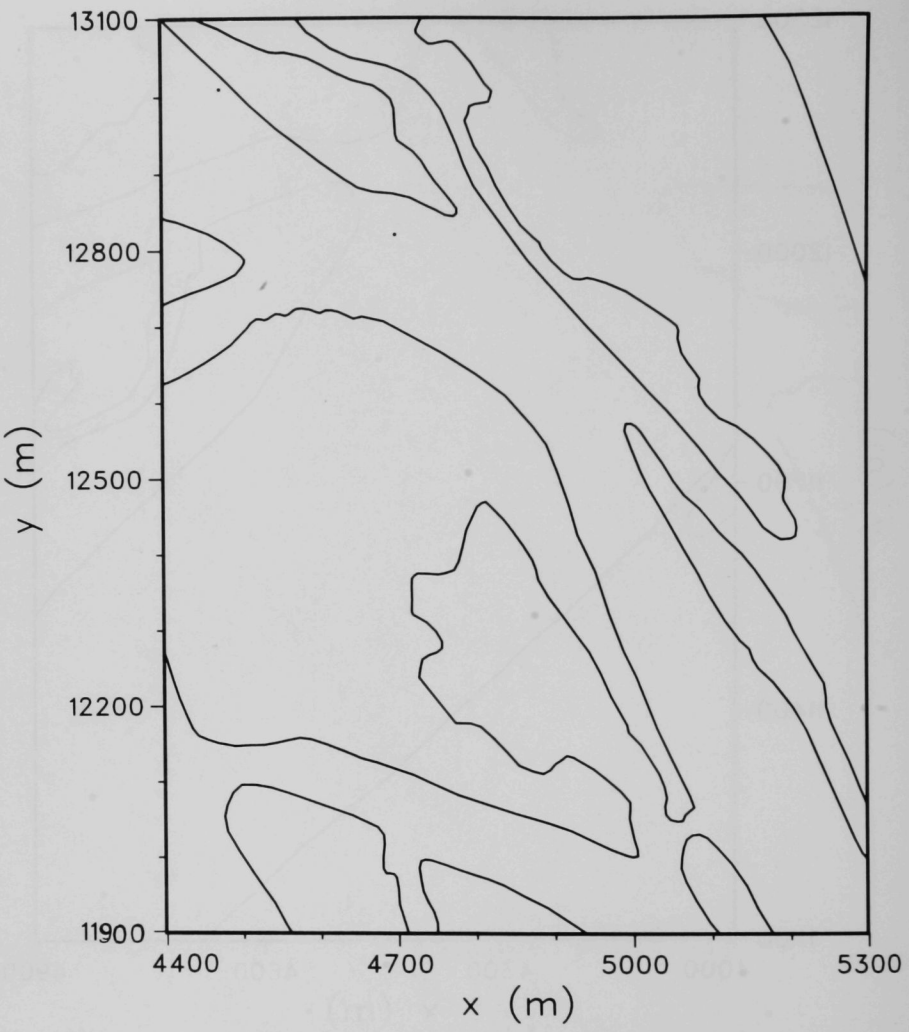

FIGURE A.13 Bottom Sampling Locations and Dyed Sand Counts in Region d of the Gordon's Ferry Site for Survey I

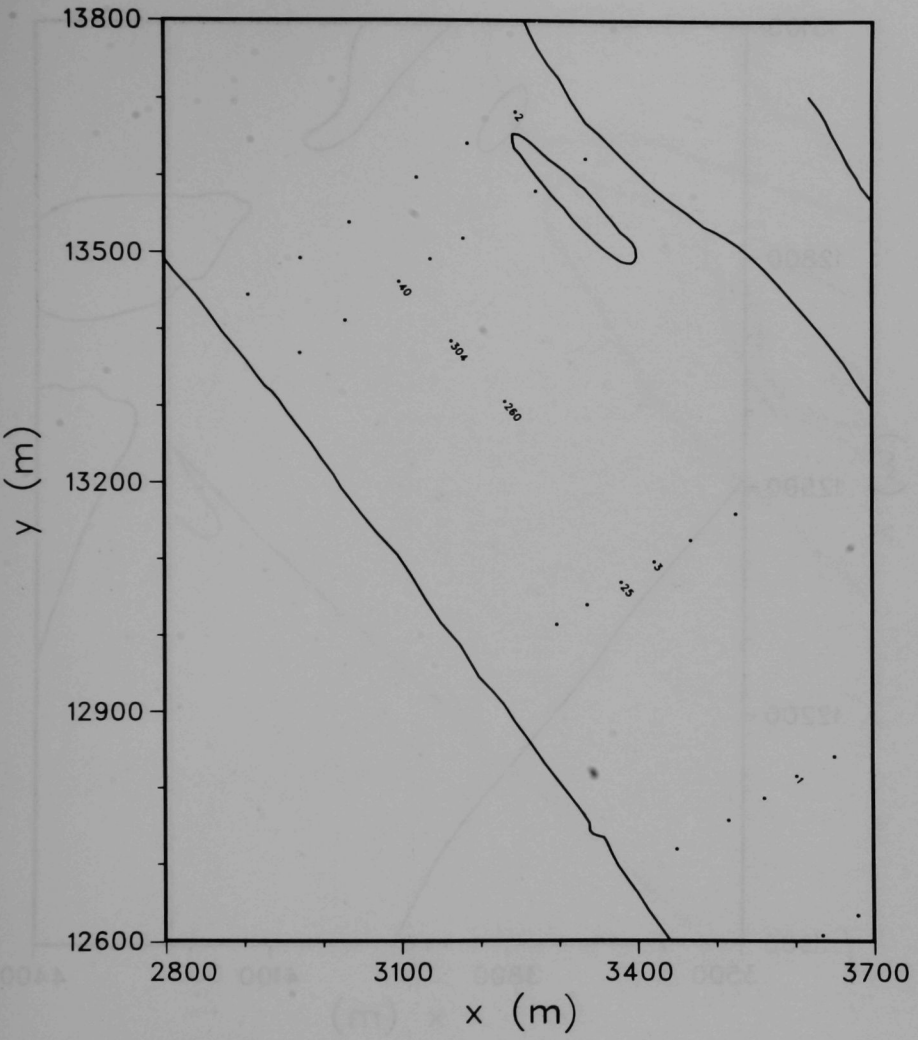

FIGURE A.14 Bottom Sampling Locations and Dyed Sand Counts in Region a of the Gordon's Ferry Site for Survey II

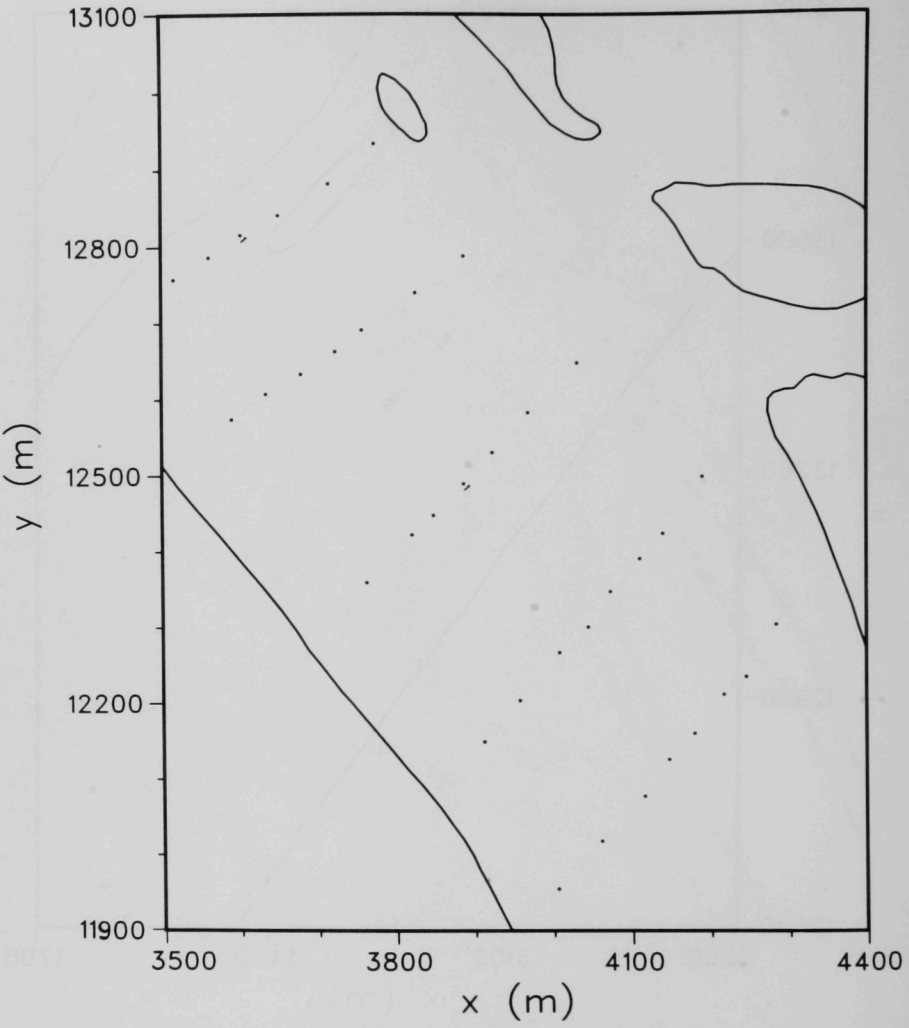

FIGURE A.15 Bottom Sampling Locations and Dyed Sand Counts in Region b of the Gordon's Ferry Site for Survey II

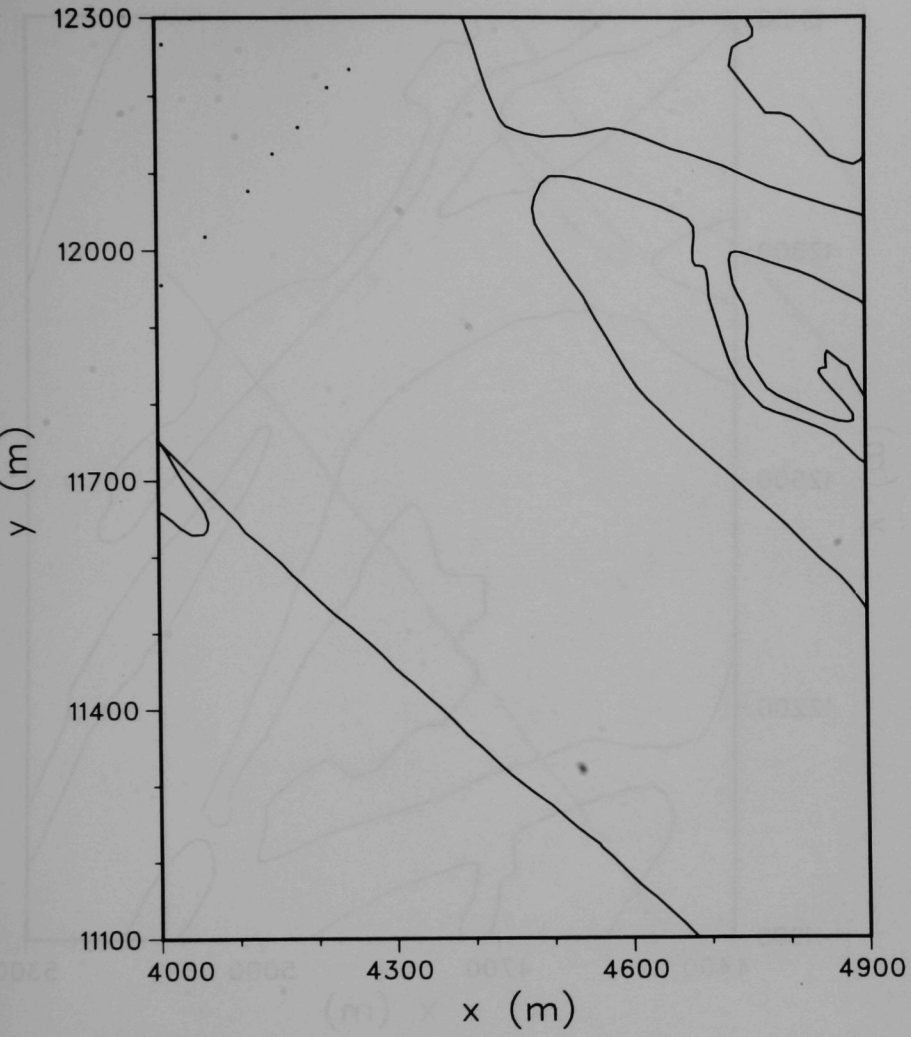

FIGURE A.16 Bottom Sampling Locations and Dyed Sand Counts in Region c of the Gordon's Ferry Site for Survey II

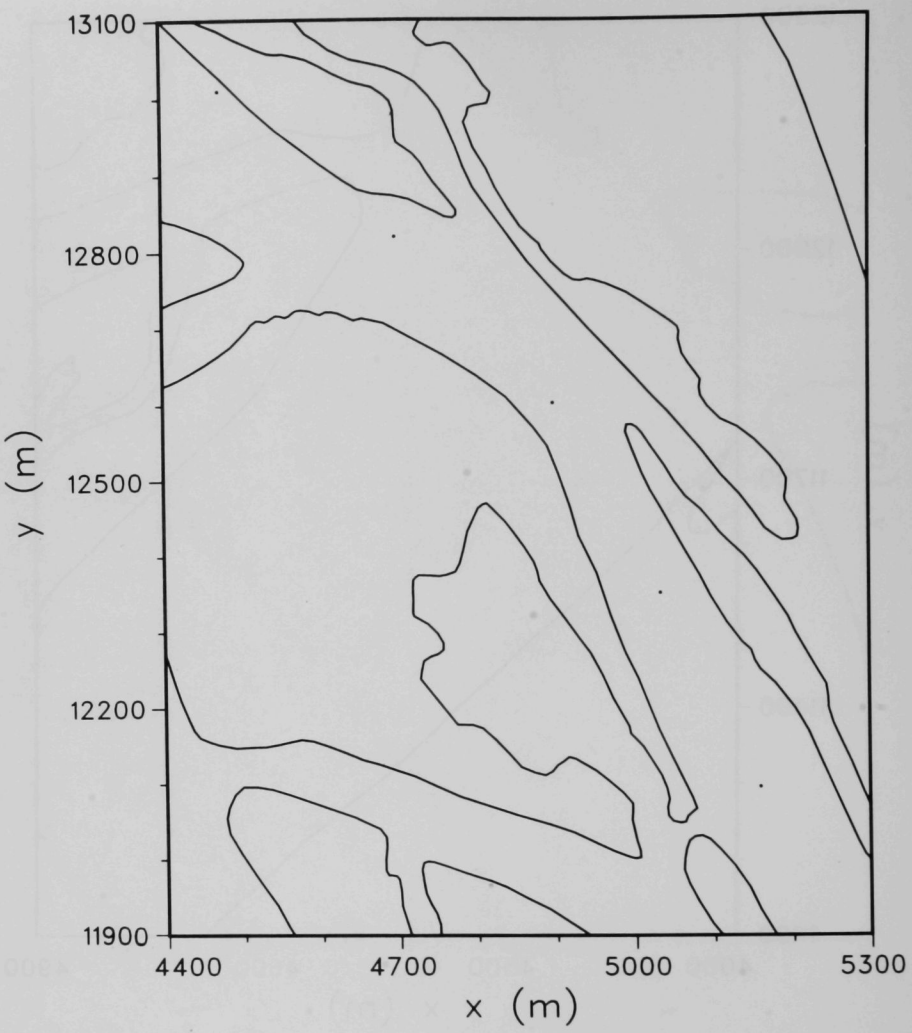

FIGURE A.17 Bottom Sampling Locations and Dyed Sand Counts in Region d of the Gordon's Ferry Site for Survey II

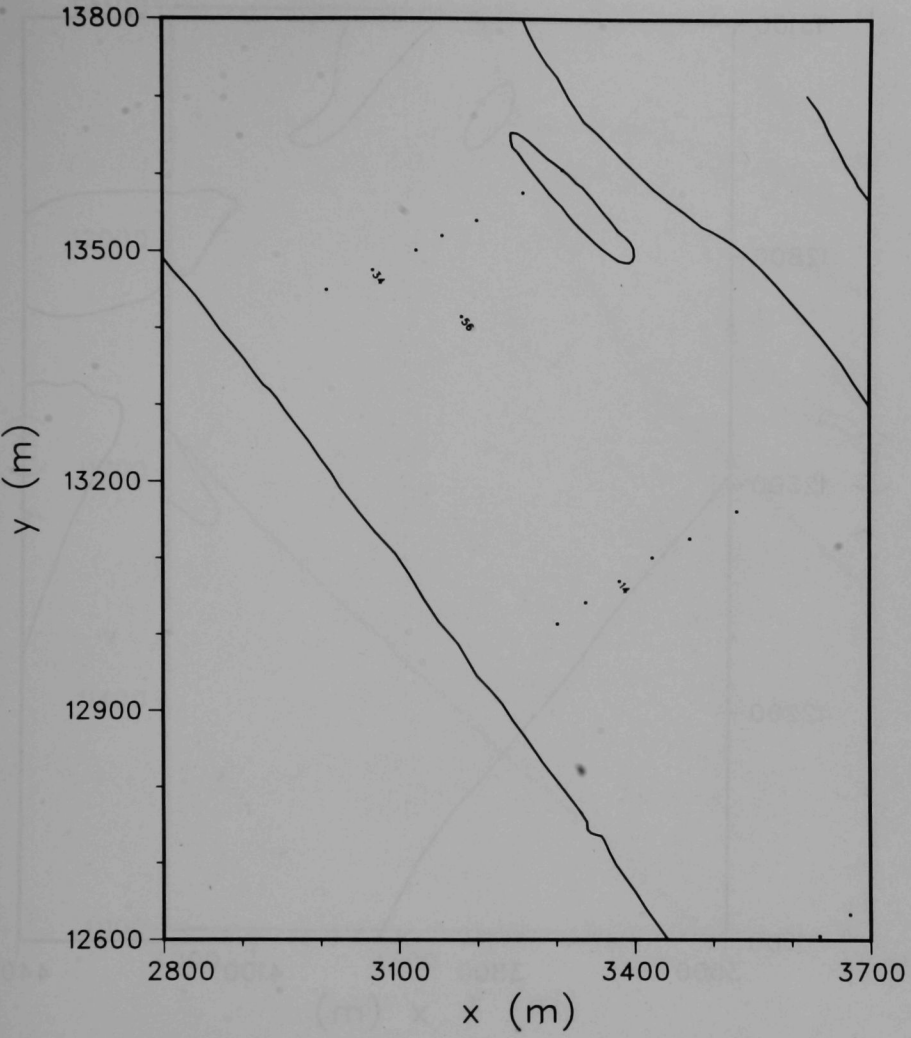

FIGURE A.18 Bottom Sampling Locations and Dyed Sand Counts in Region a of the Gordon's Ferry Site for Survey III

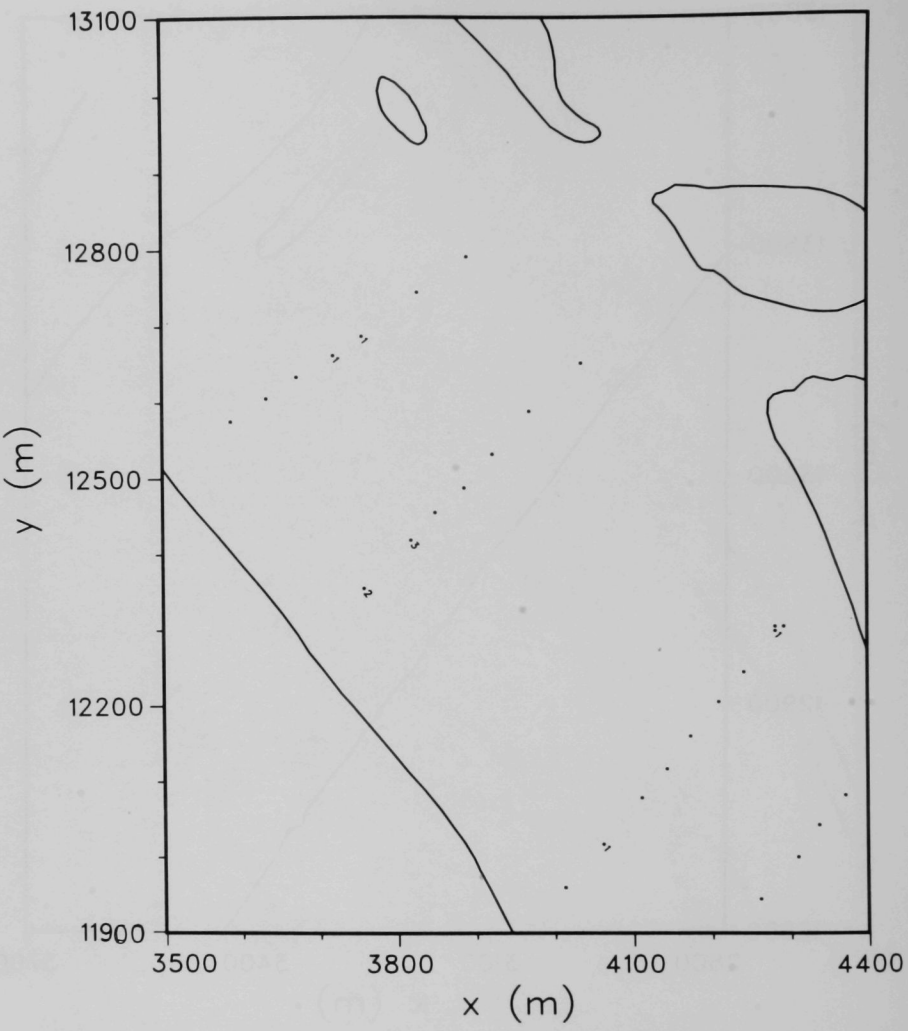

FIGURE A.19 Bottom Sampling Locations and Dyed Sand Counts in Region b of the Gordon's Ferry Site for Survey III

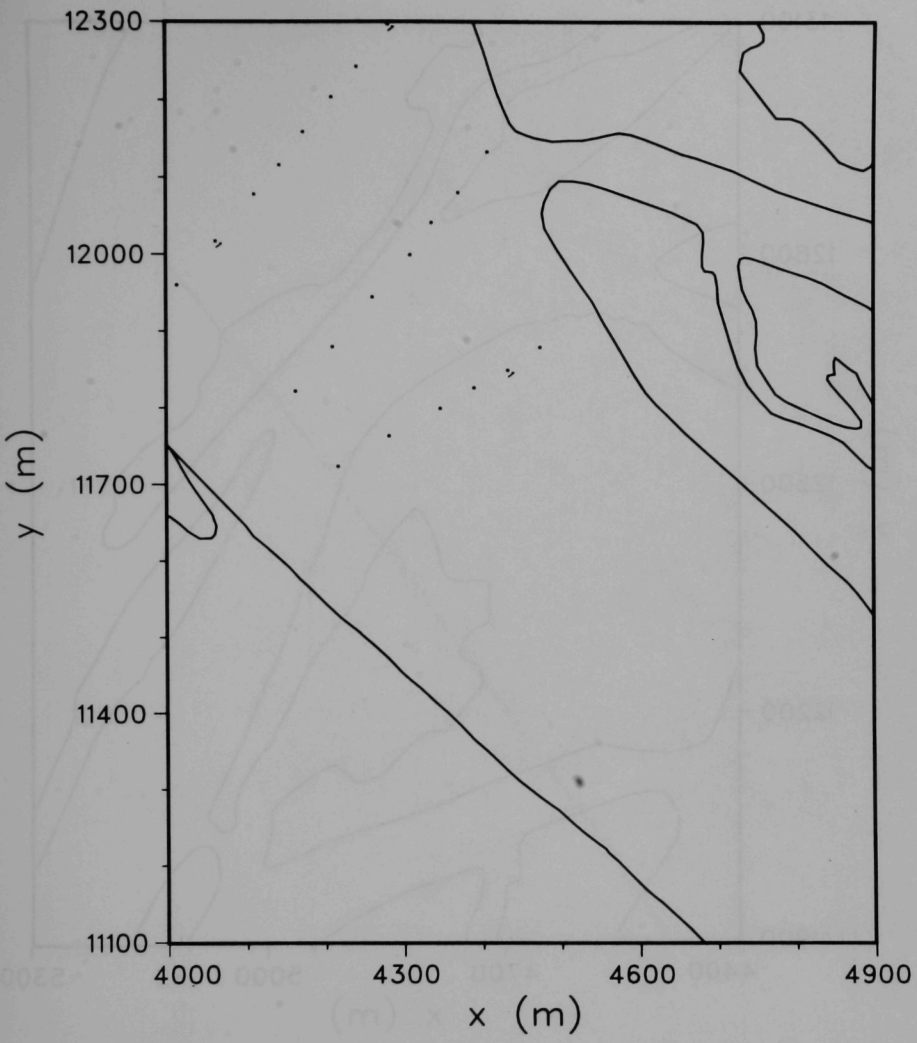

FIGURE A.20 Bottom Sampling Locations and Dyed Sand Counts in Region c of the Gordon's Ferry Site for Survey III

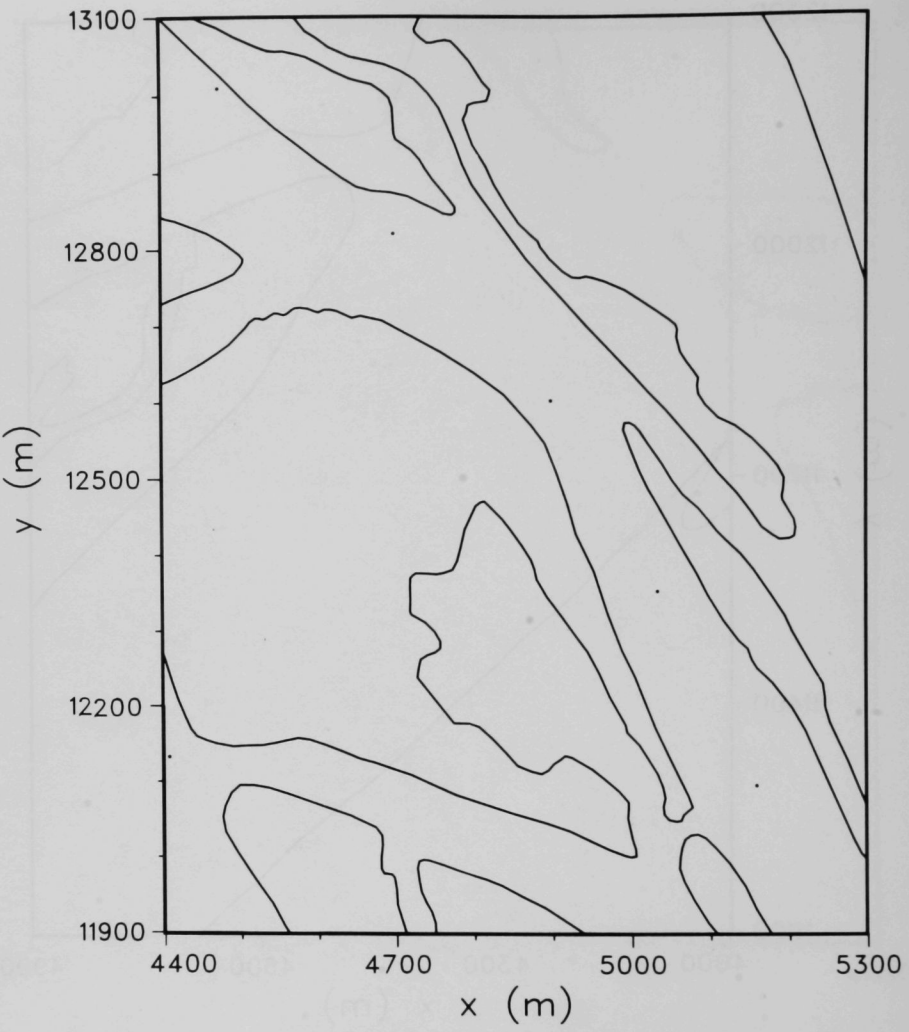

FIGURE A.21 Bottom Sampling Locations and Dyed Sand Counts in Region d of the Gordon's Ferry Site for Survey III

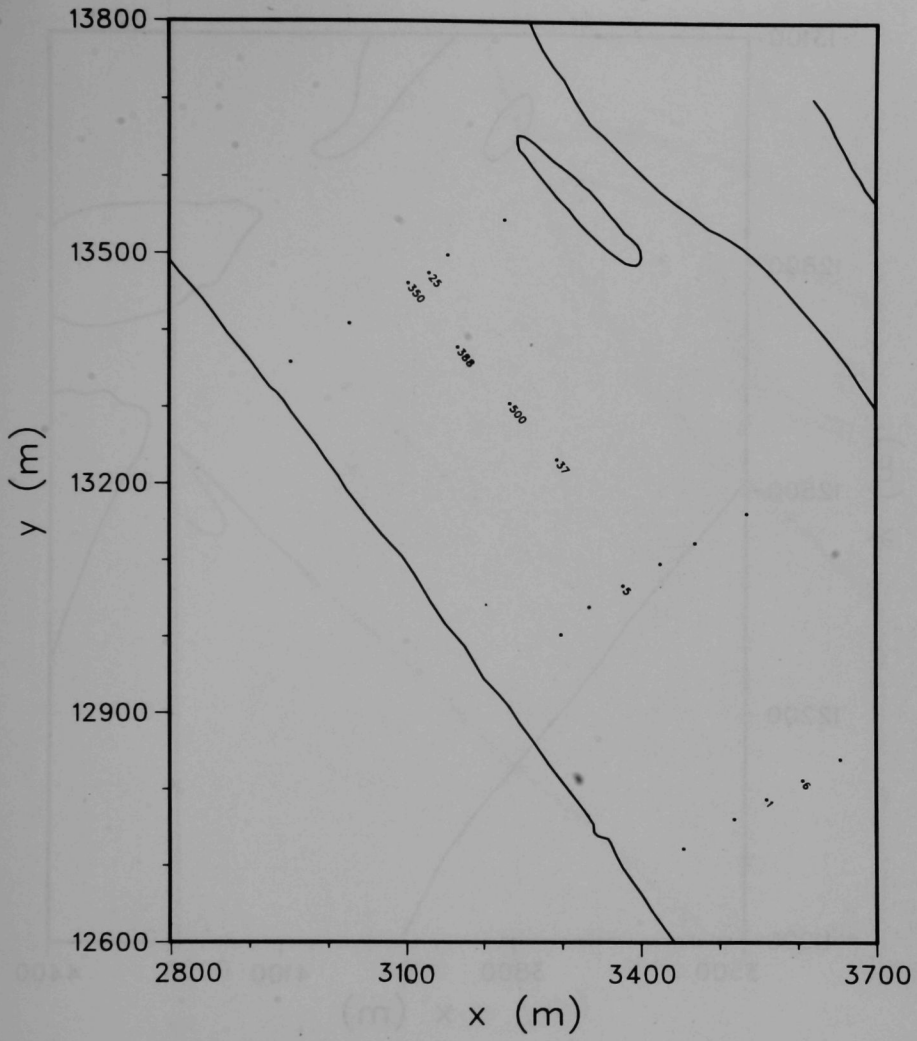

FIGURE A.22 Bottom Sampling Locations and Dyed Sand Counts in Region a of the Gordon's Ferry Site for Survey IV

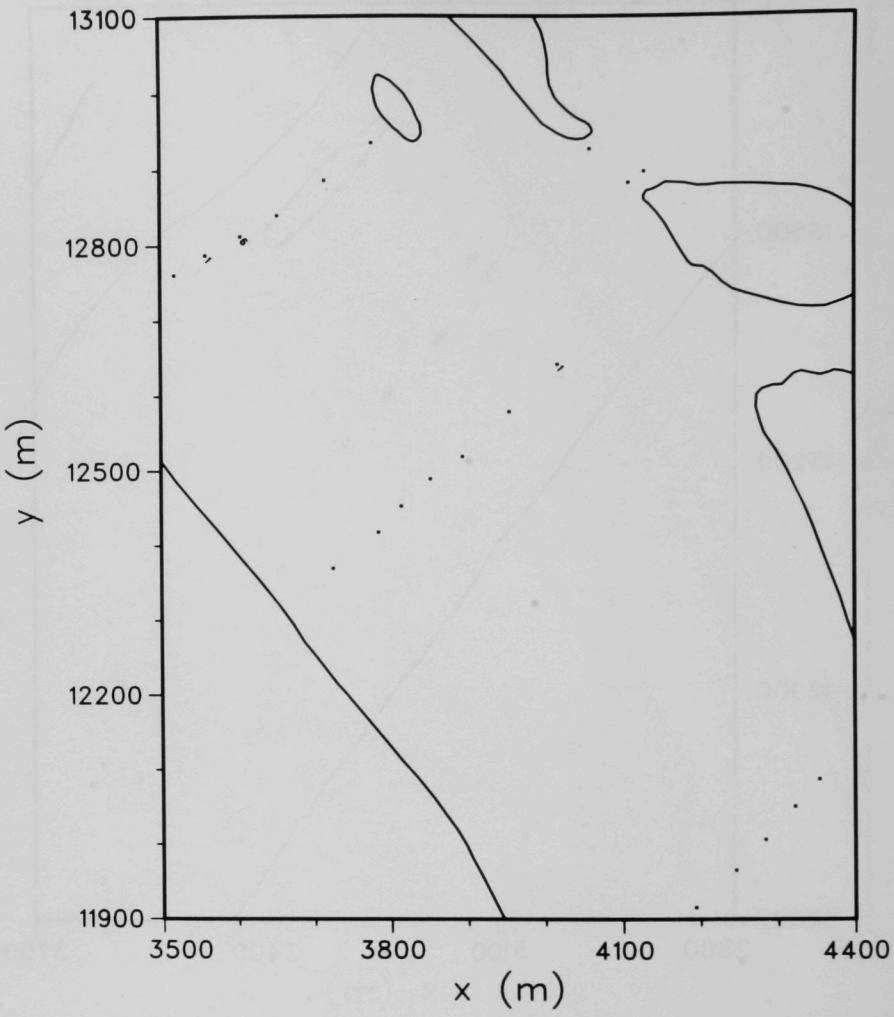

FIGURE A.23 Bottom Sampling Locations and Dyed Sand Counts in Region b of the Gordon's Ferry Site for Survey IV

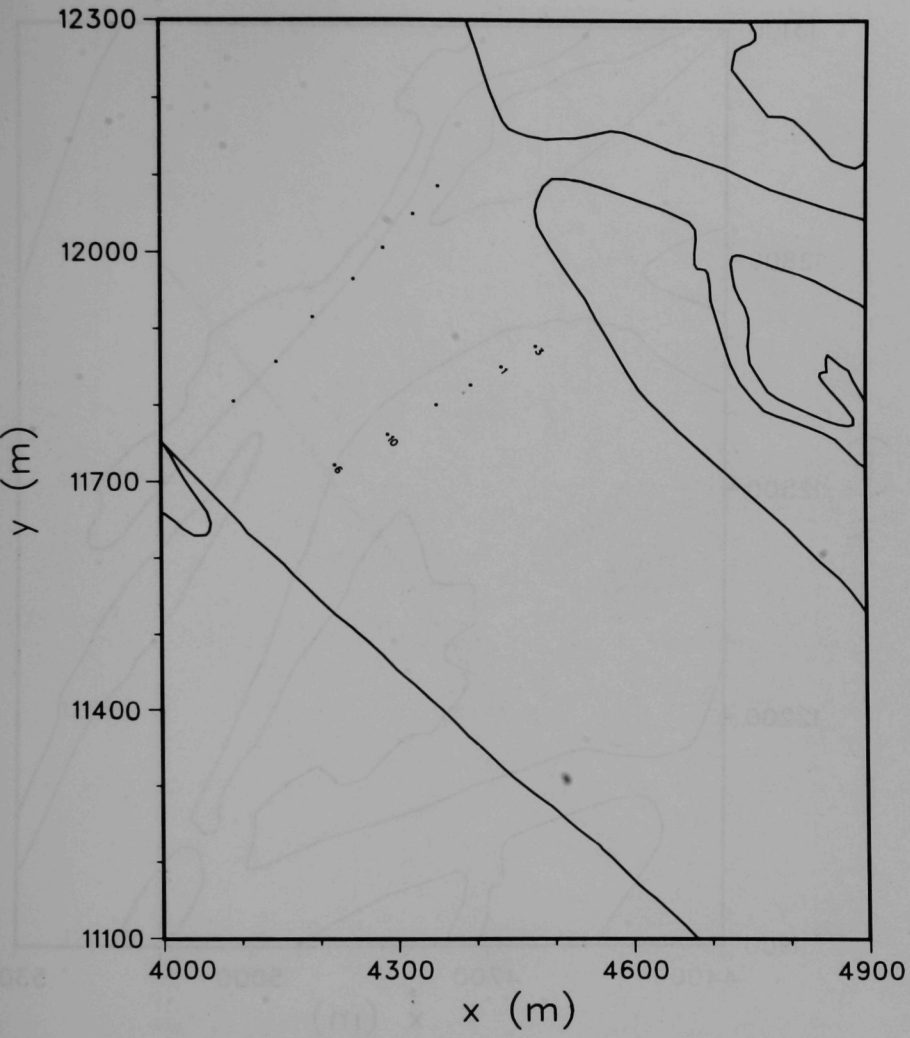

FIGURE A.24 Bottom Sampling Locations and Dyed Sand Counts in Region c of the Gordon's Ferry Site for Survey IV

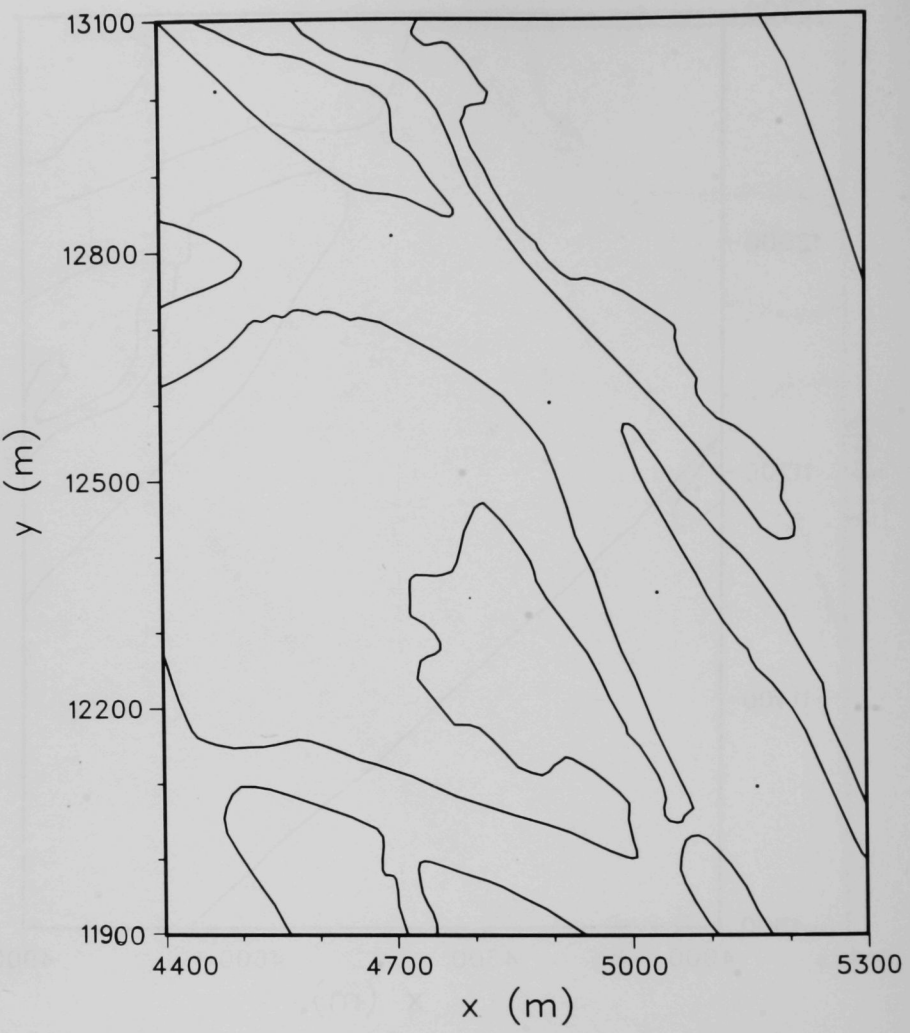

FIGURE A.25 Bottom Sampling Locations and Dyed Sand Counts in Region d of the Gordon's Ferry Site for Survey IV

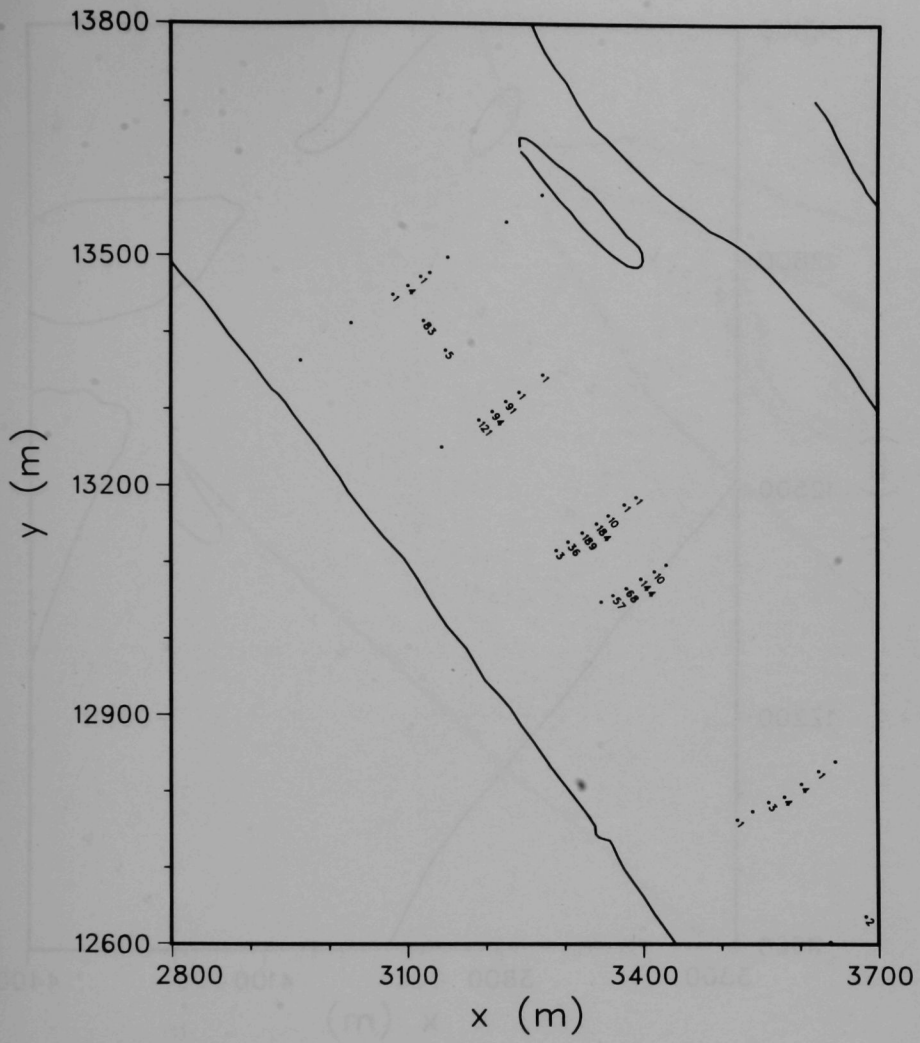

FIGURE A.26 Bottom Sampling Locations and Dyed Sand Counts in Region a of the Gordon's Ferry Site for Survey V

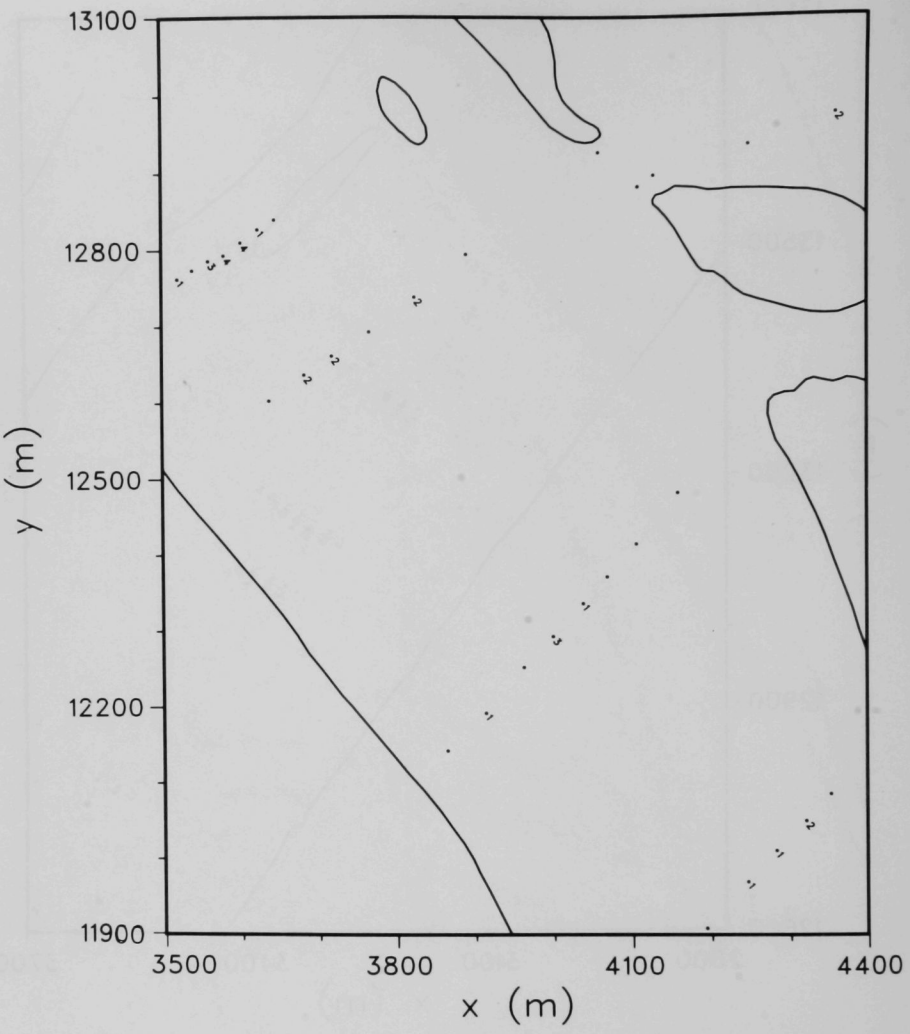

FIGURE A.27 Bottom Sampling Locations and Dyed Sand Counts in Region b of the Gordon's Ferry Site for Survey V

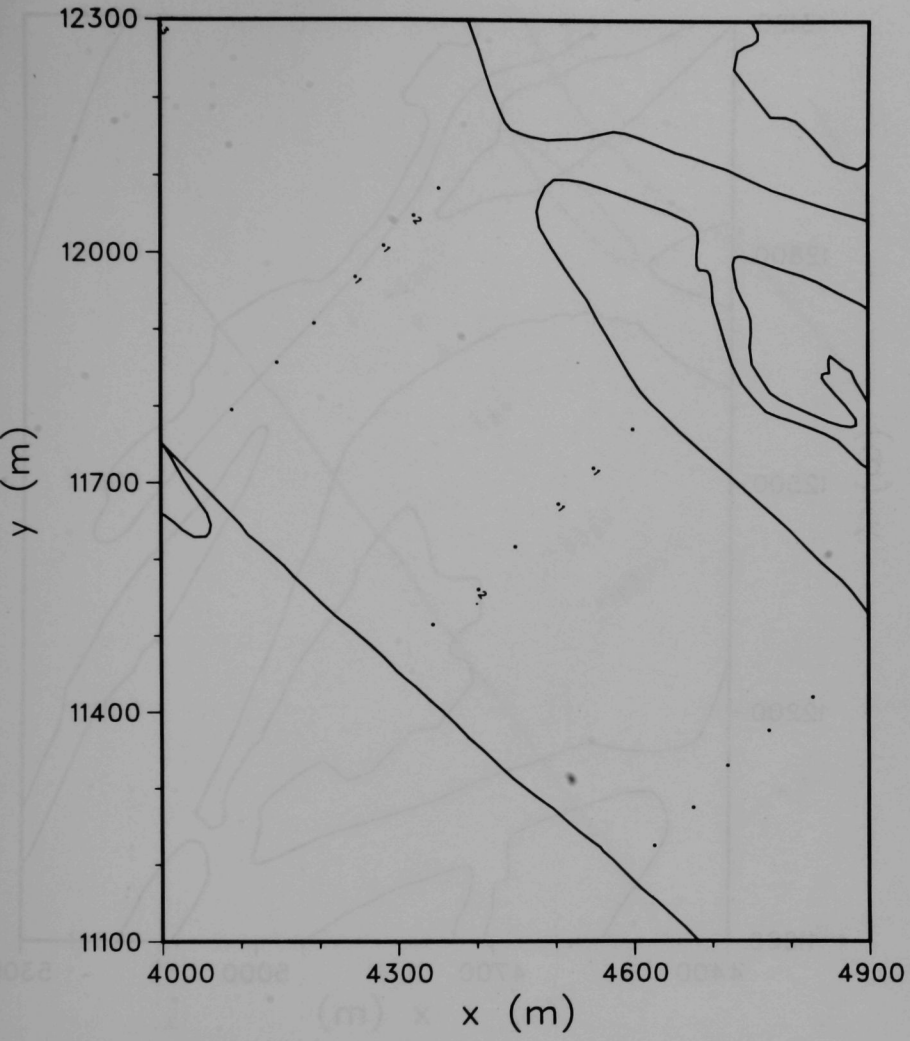

FIGURE A.28 Bottom Sampling Locations and Dyed Sand Counts in Region c of the Gordon's Ferry Site for Survey V

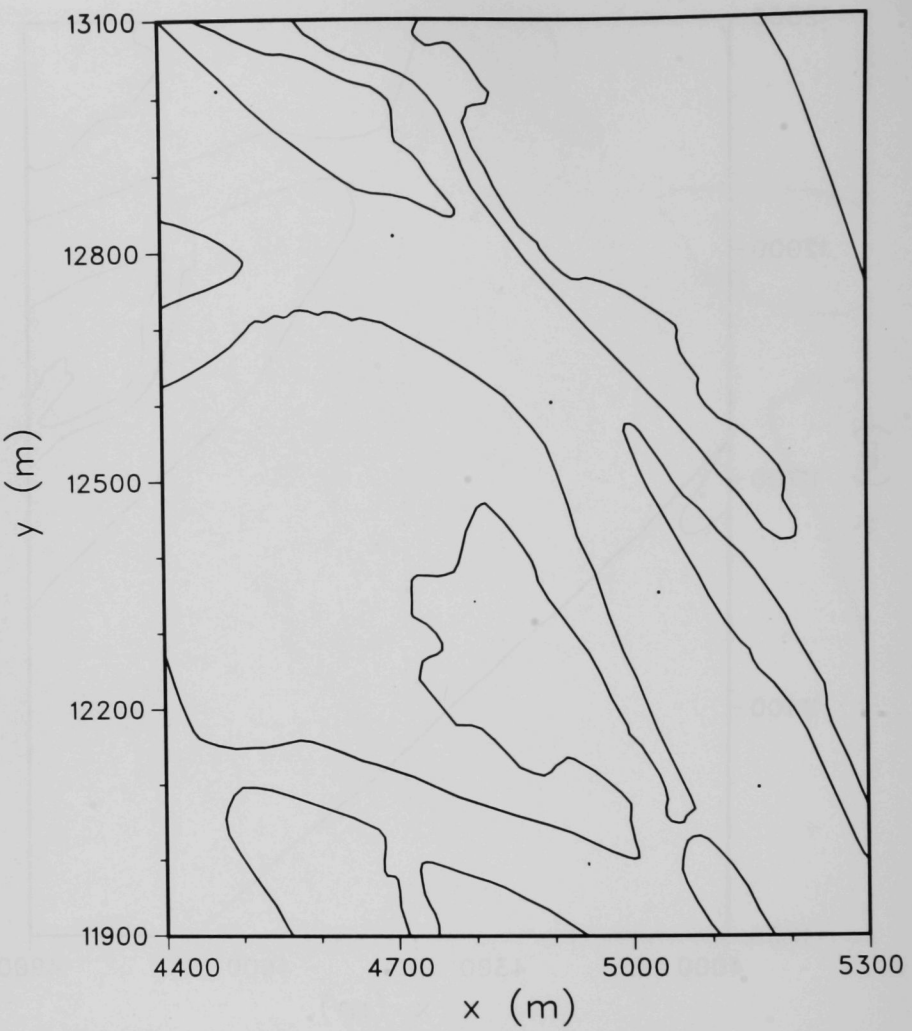

FIGURE A.29 Bottom Sampling Locations and Dyed Sand Counts in Region d of the Gordon's Ferry Site for Survey V

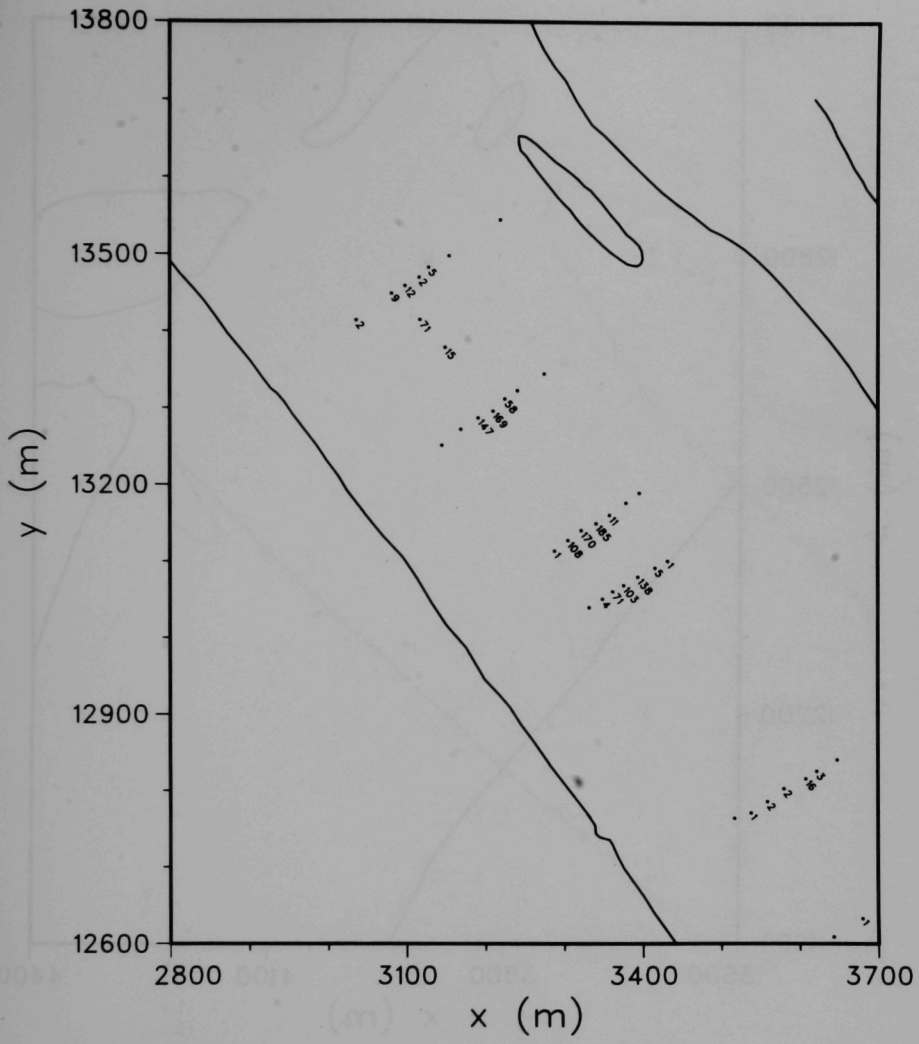

FIGURE A.30 Bottom Sampling Locations and Dyed Sand Counts in Region a of the Gordon's Ferry Site for Survey VI

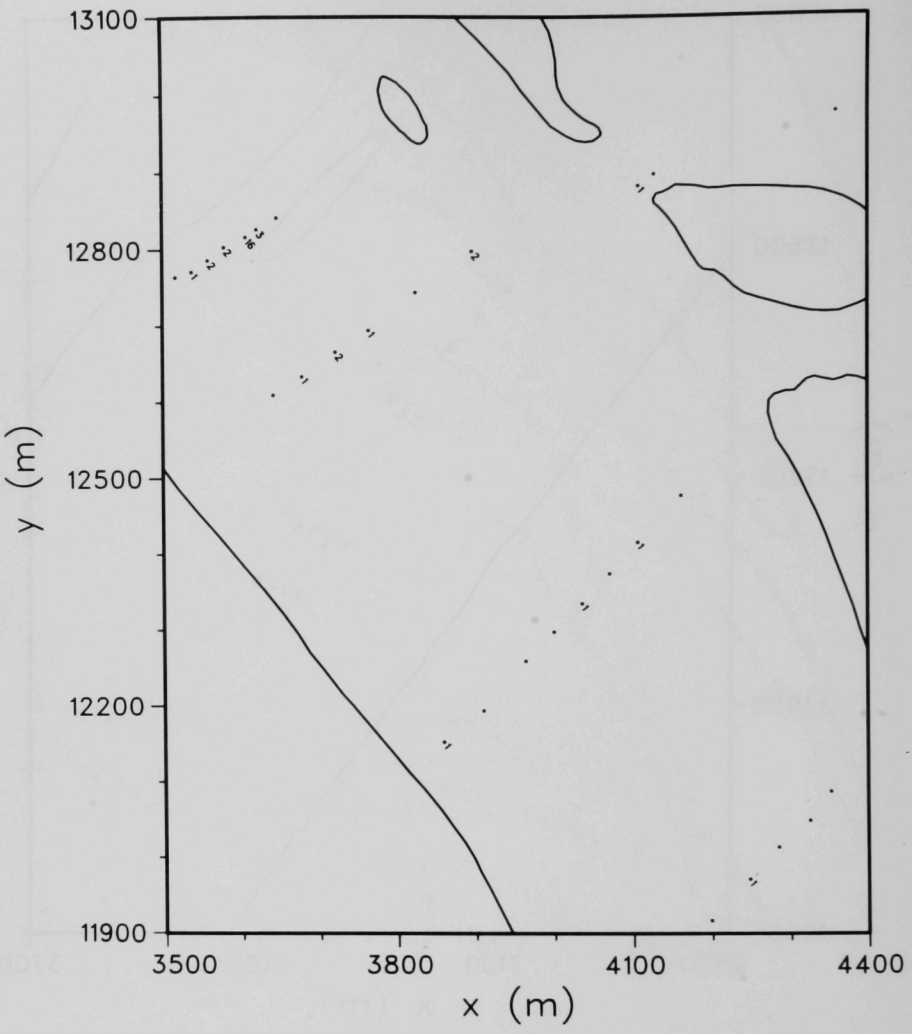

FIGURE A.31 Bottom Sampling Locations and Dyed Sand Counts in Region b of the Gordon's Ferry Site for Survey VI

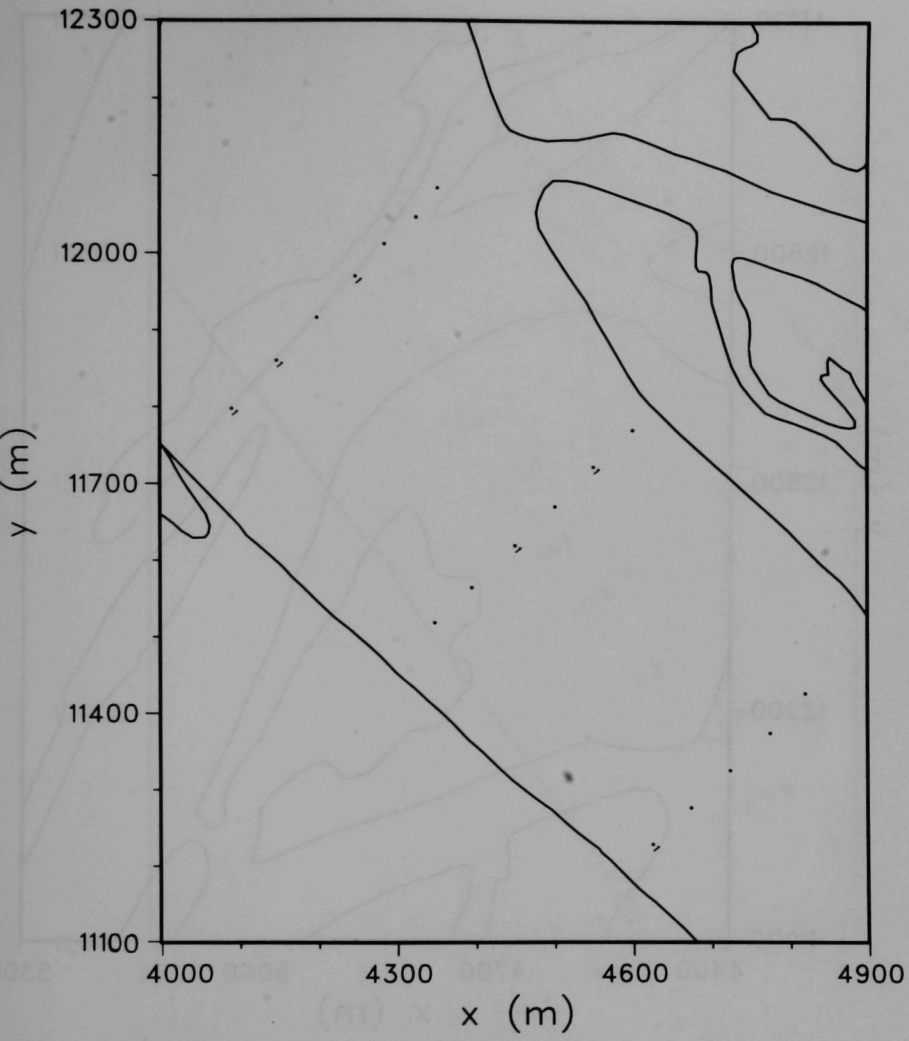

FIGURE A.32 Bottom Sampling Locations and Dyed Sand Counts in Region c of the Gordon's Ferry Site for Survey VI

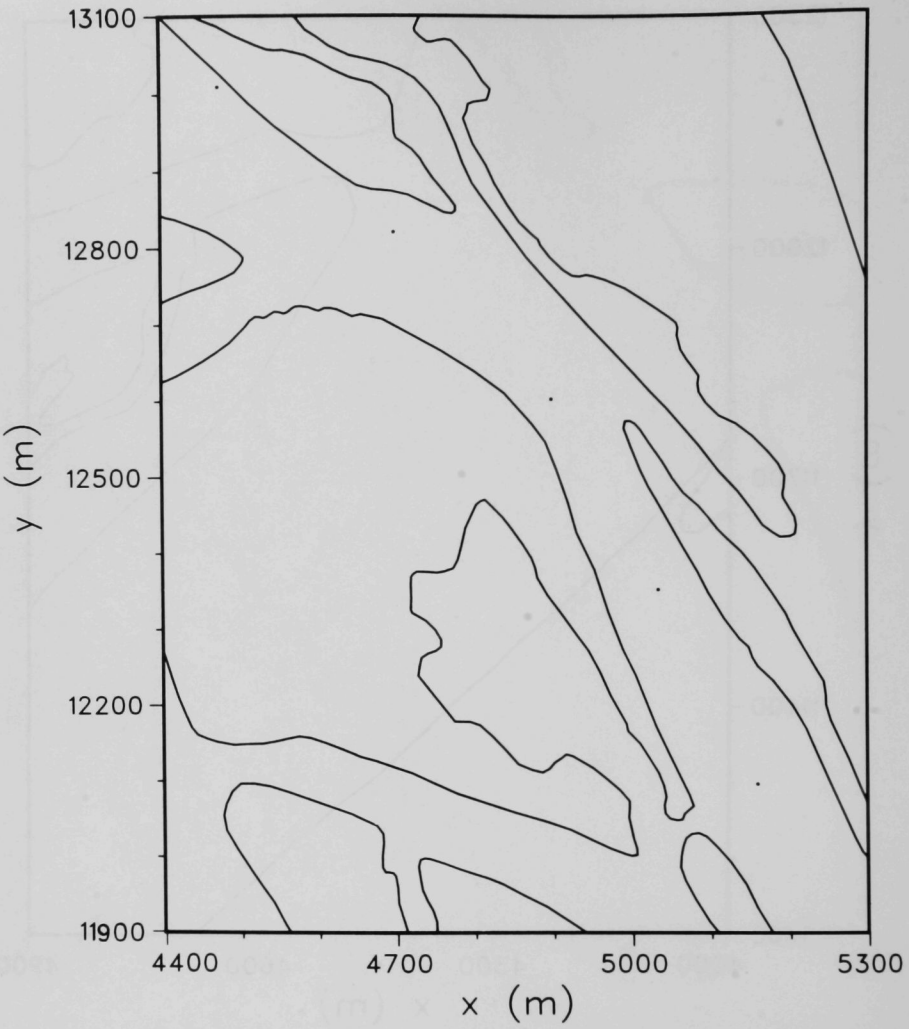

FIGURE A.33 Bottom Sampling Locations and Dyed Sand Counts in Region d of the Gordon's Ferry Site for Survey VI

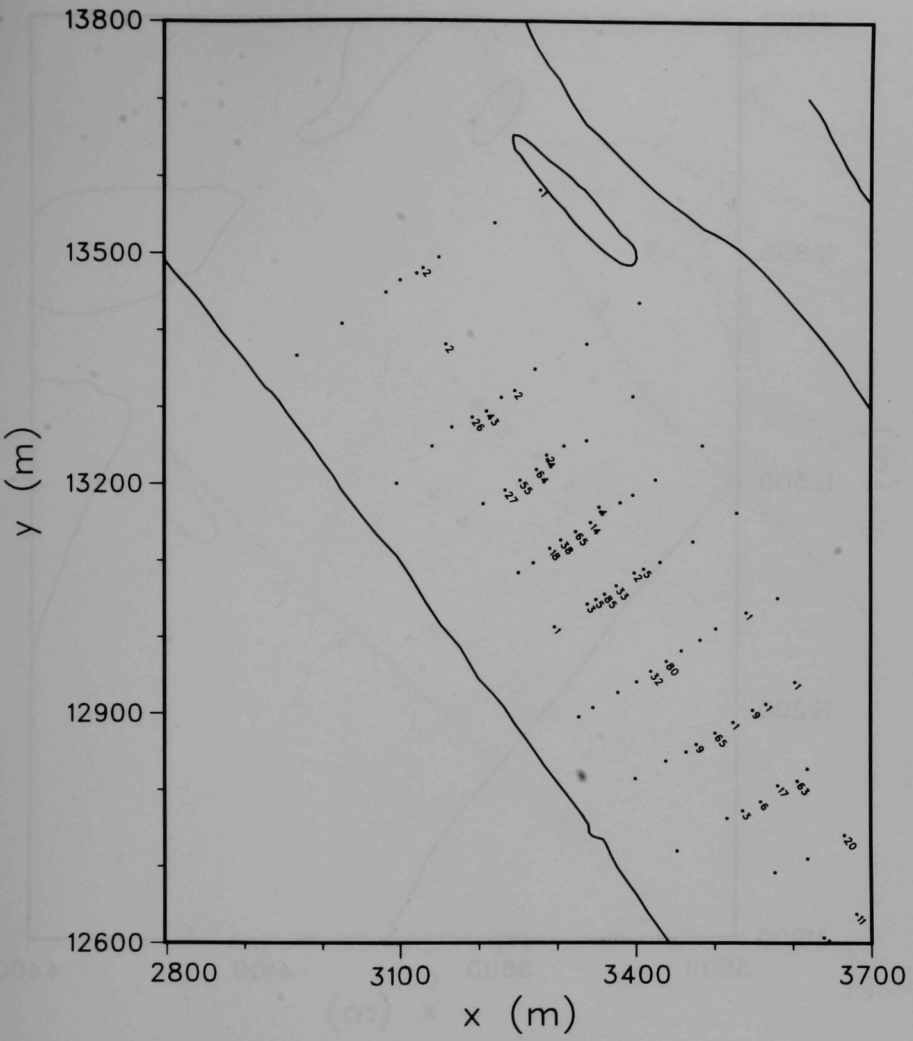

FIGURE A.34 Bottom Sampling Locations and Dyed Sand Counts in Region a of the Gordon's Ferry Site for Survey VII

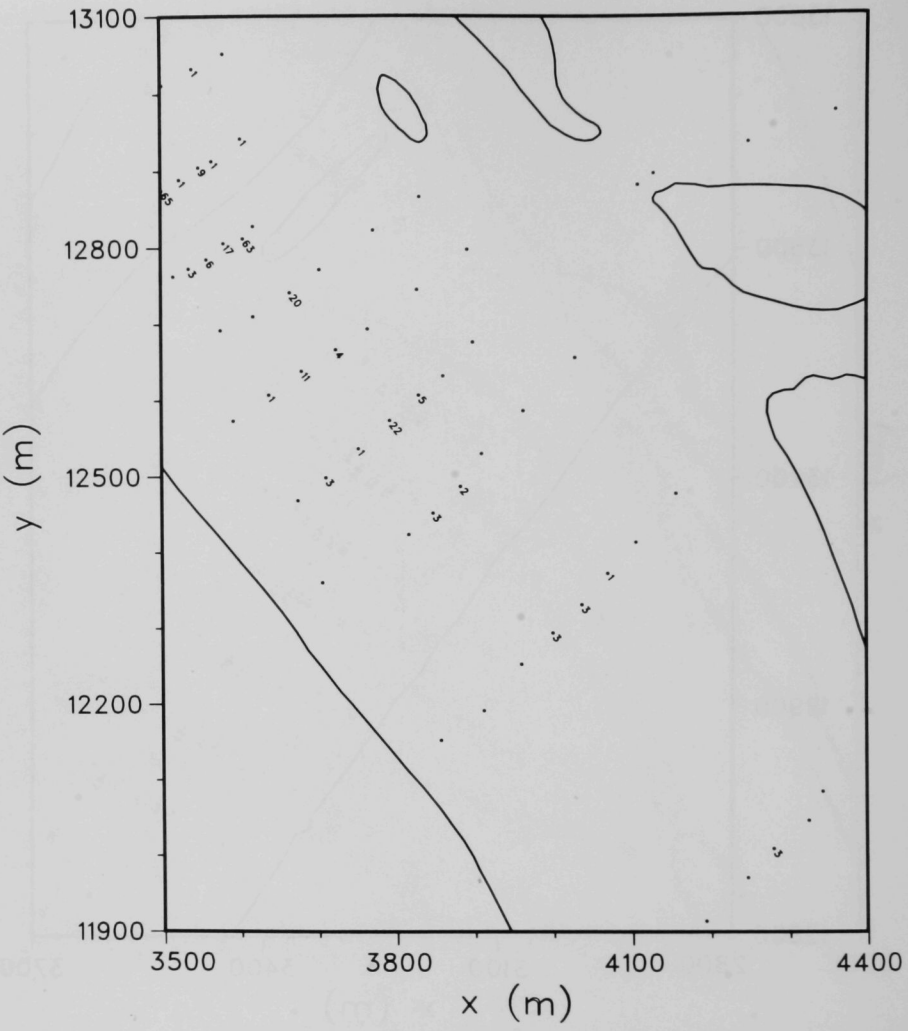

FIGURE A.35 Bottom Sampling Locations and Dyed Sand Counts in Region b of the Gordon's Ferry Site for Survey VII

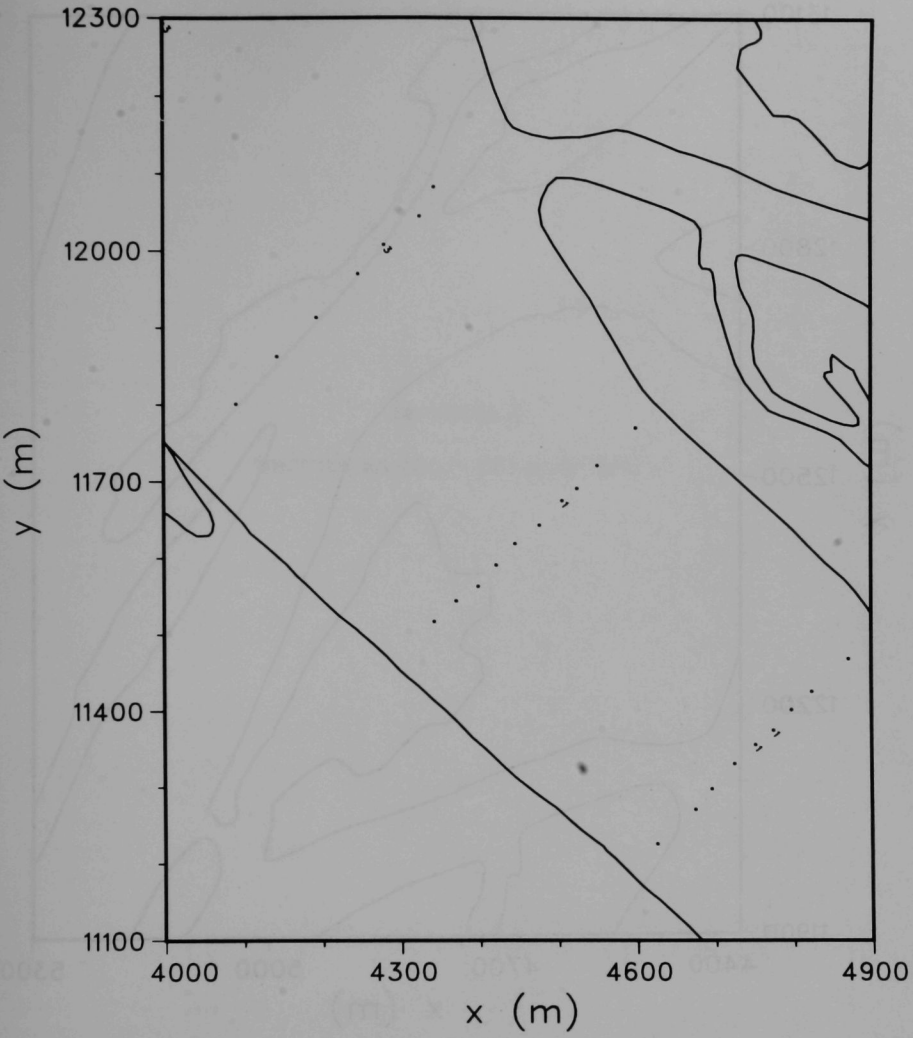

FIGURE A.36 Bottom Sampling Locations and Dyed Sand Counts in Region c of the Gordon's Ferry Site for Survey VII

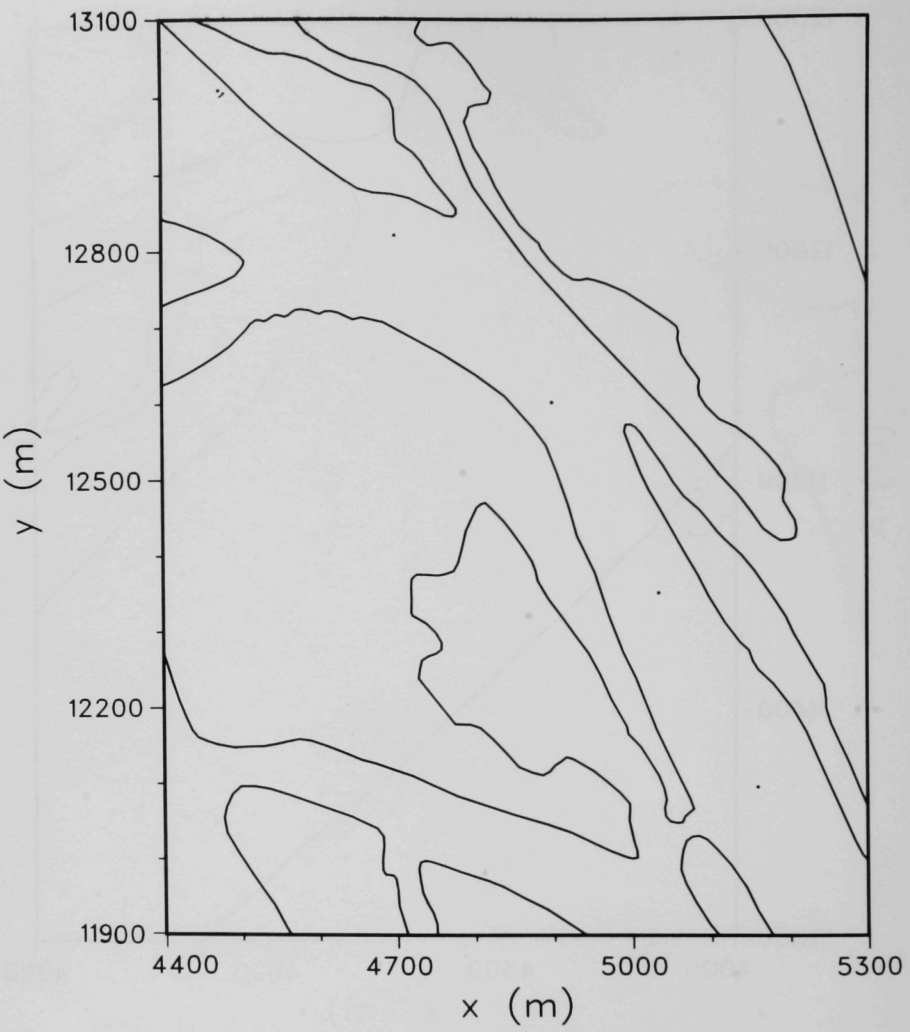

FIGURE A.37 Bottom Sampling Locations and Dyed Sand Counts in Region d of the Gordon's Ferry Site for Survey VII

APPENDIX B

WHITNEY ISLAND — DETAILED DATA

APPENDIX B

WHITNEY ISLAND — DETAILED DATA

The results and some of the data from five postdisposal surveys at the Whitney Island site were presented and discussed in Sec. 4. The complete sets of bathymetric data and dyed sand data for each of these surveys are given in Secs. B.1 and B.2 of this appendix.

B.1 BATHYMETRIC DATA FROM THE WHITNEY ISLAND DISPOSAL SITE

The complete bathymetric data from the predisposal survey and the five postdisposal surveys at Whitney Island are presented in Figs. B.1-B.11. The approximate boat paths for each set of transects are shown in the upper left-hand quadrant of each figure. The bottom profiles for the transverse transects (approximately parallel to the x axis) are presented in sequence starting in the upper right-hand quadrant with the transect farthest upstream (northernmost) and proceeding downstream (southward). The profiles for the individual transects are plotted starting from the Missouri (west) end of each transect. The bottom profiles for the longitudinal transects (approximately parallel to the y axis) are then presented in sequence starting with the transect closest to the Illinois (east) shore and proceeding toward the Missouri (west) shore. The profiles for individual transects are plotted starting from the downstream (south) end of each transect.

B.2 DYED SAND DATA FROM THE WHITNEY ISLAND DISPOSAL SITE

The locations of the bottom-sampling stations for each of the five postdisposal surveys at Whitney Island are presented in Sec. B.2. The study area was divided into three regions (a, b, and c) for presentation purposes as shown in Fig. B.12. Region a encompasses the original disposal area, region b includes the entrance to Stillwell Slough and the main-channel area between the disposal site and the slough entrance, and region c covers the upstream portion of Stillwell Slough and the main-channel area downstream of the slough entrance. The sampling locations for Surveys I-V are shown in Figs. B.13-B.27. The number of individual dyed sand grains, if any, observed in the photographs of the surface of the 23 cm × 23 cm sample tray illuminated by ultraviolet light is given adjacent to each sampling location. The details of the sampling and photographing procedure and the statistical significance of the number of dyed sand grains observed in any one sample were discussed in Sec. 2.

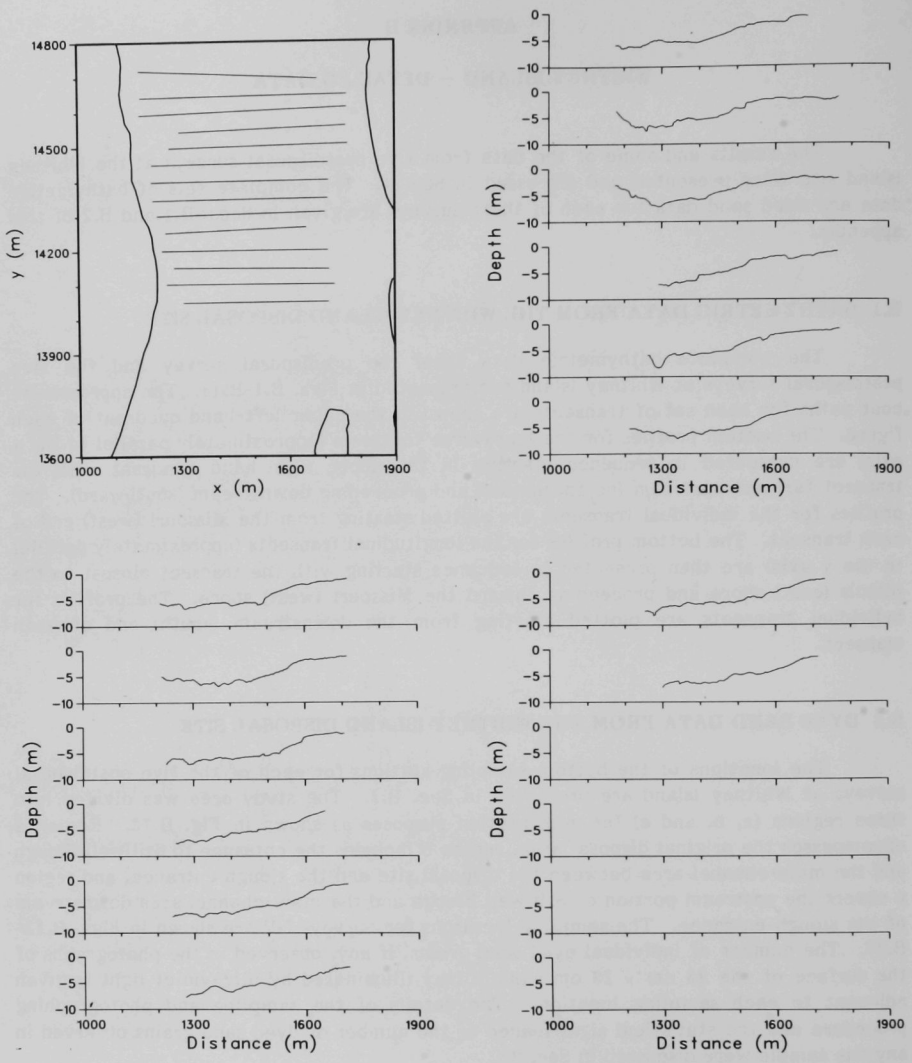

FIGURE B.1 Bathymetric Transects and Transverse Bottom Profiles for the Predisposal Survey at Whitney Island on September 14, 1982

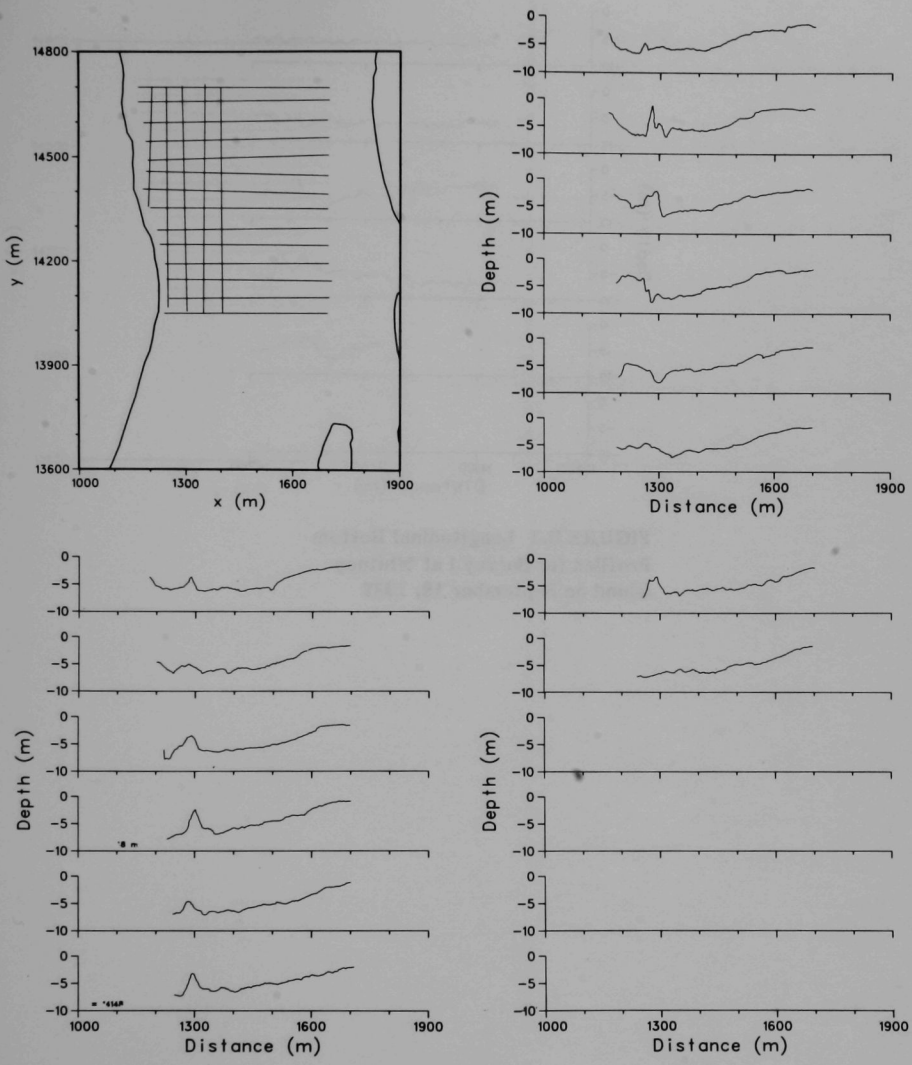

FIGURE B.2 Bathymetric Transects and Transverse Bottom Profiles for Survey I at Whitney Island on September 18, 1982

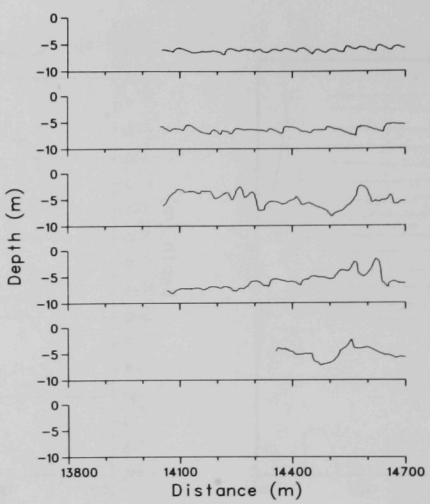

FIGURE B.3 Longitudinal Bottom Profiles for Survey I at Whitney Island on September 18, 1982

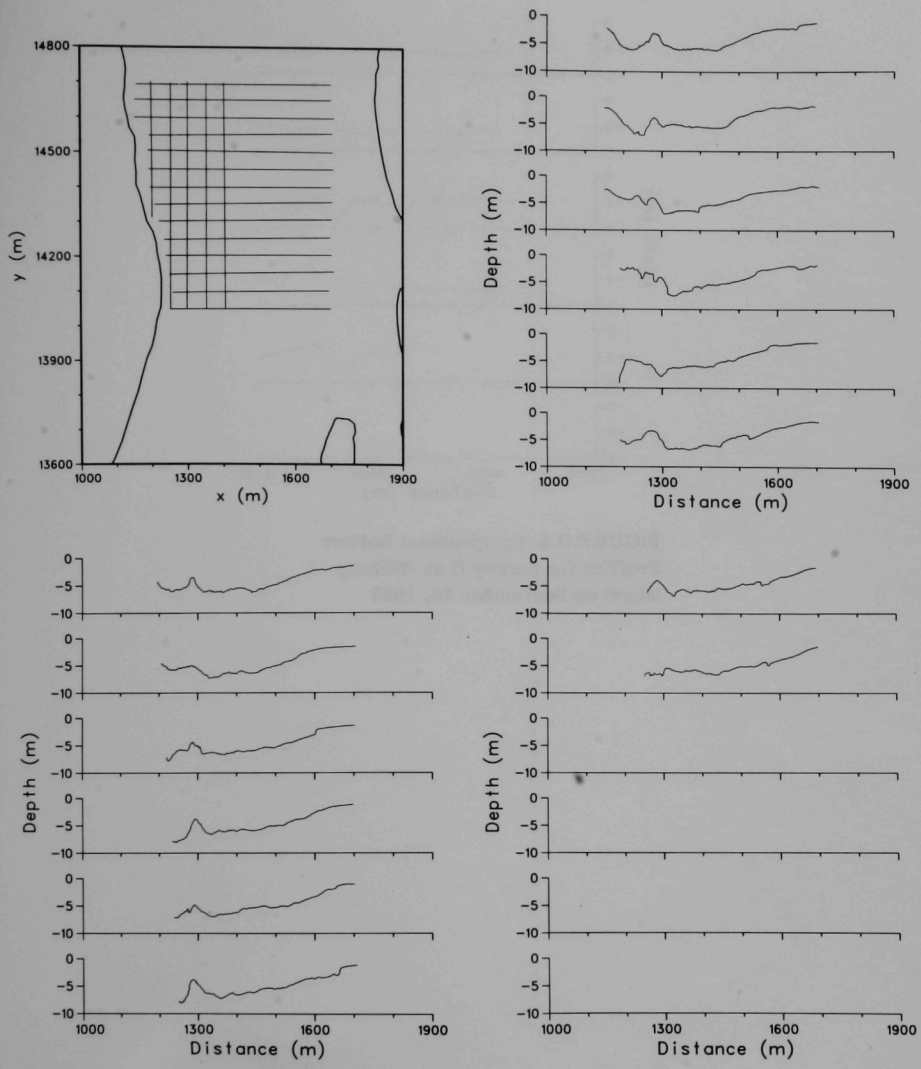

FIGURE B.4 Bathymetric Transects and Transverse Bottom Profiles for Survey II at Whitney Island on September 28, 1982

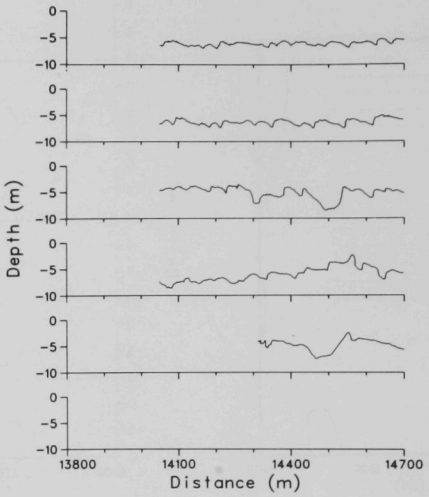

FIGURE B.5 Longitudinal Bottom Profiles for Survey II at Whitney Island on September 28, 1982

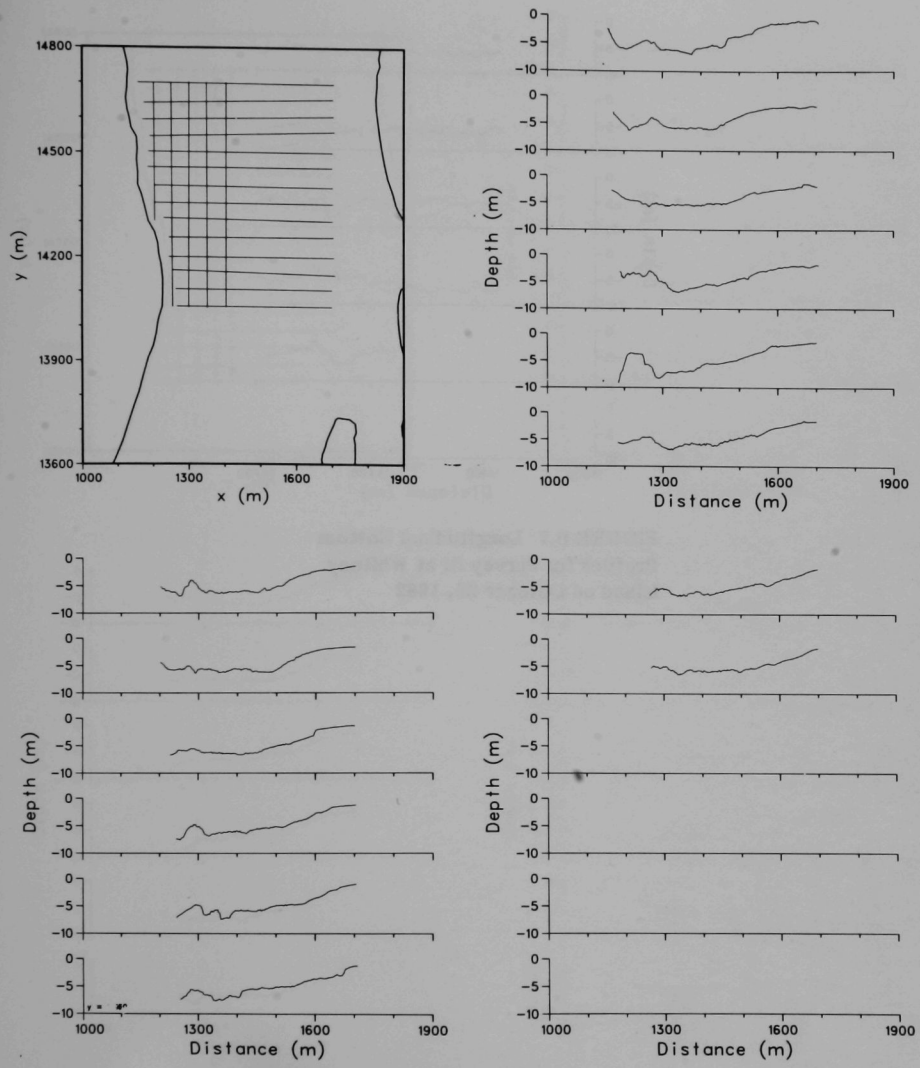

FIGURE B.6 Bathymetric Transects and Transverse Bottom Profiles for Survey III at Whitney Island on October 26, 1982

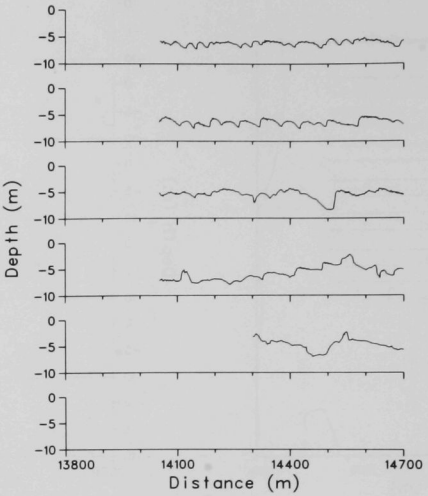

FIGURE B.7 Longitudinal Bottom Profiles for Survey III at Whitney Island on October 26, 1982

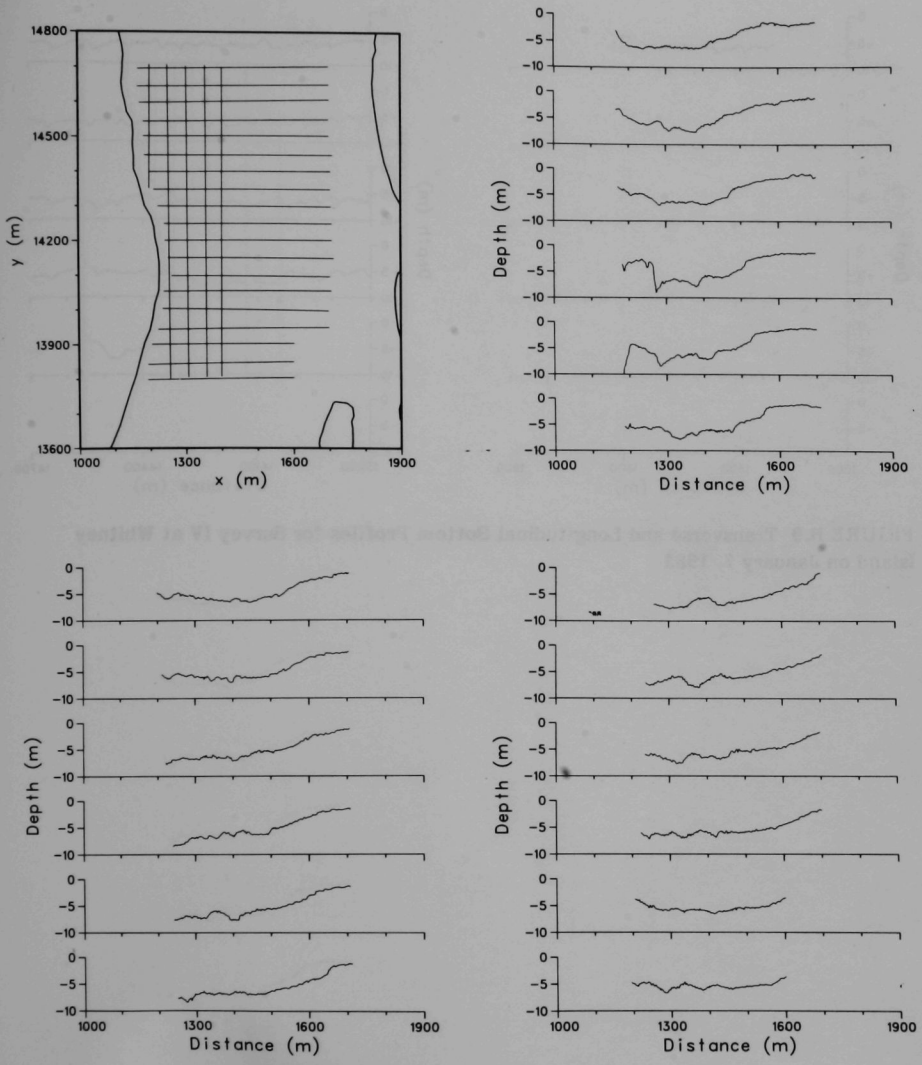

FIGURE B.8 Bathymetric Transects and Transverse Bottom Profiles for Survey IV at Whitney Island on January 7, 1983

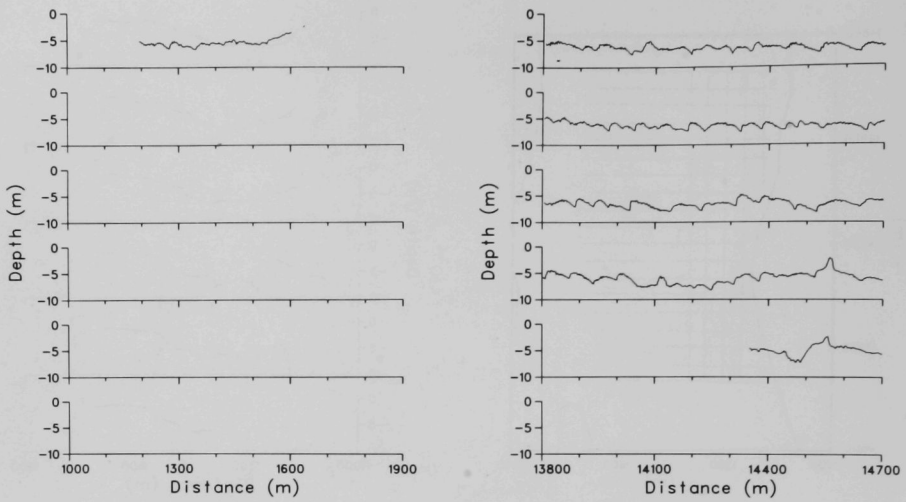

FIGURE B.9 Transverse and Longitudinal Bottom Profiles for Survey IV at Whitney Island on January 7, 1983

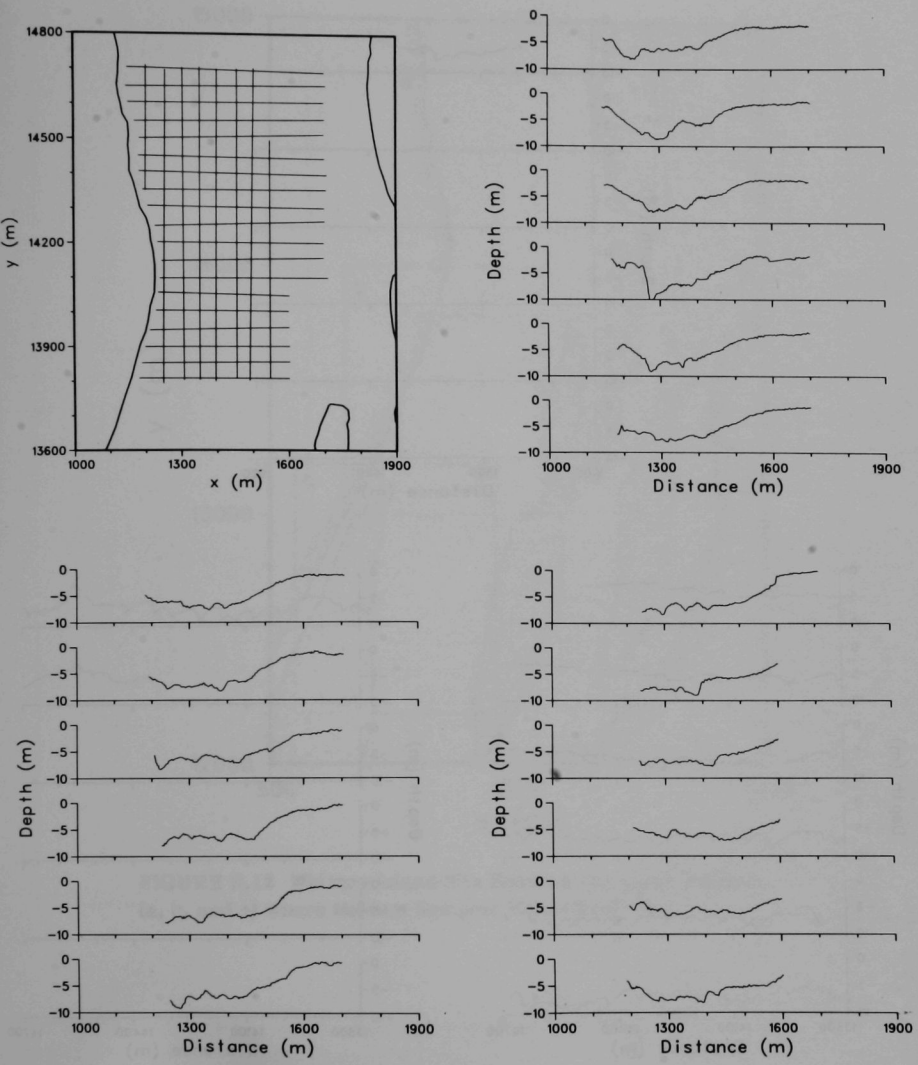

FIGURE B.10 Bathymetric Transects and Transverse Bottom Profiles for Survey V at Whitney Island on May 25, 1983

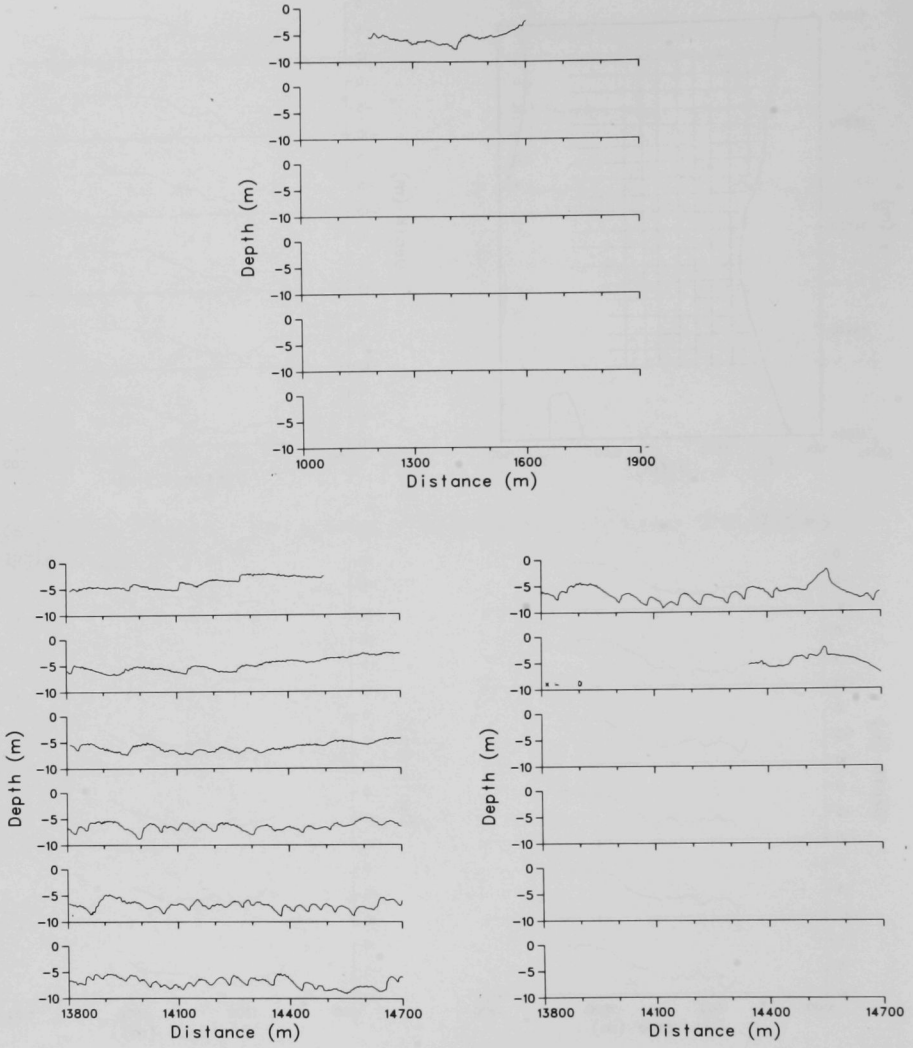

FIGURE B.11 Transverse and Longitudinal Bottom Profiles for Survey V at Whitney Island on May 25, 1983

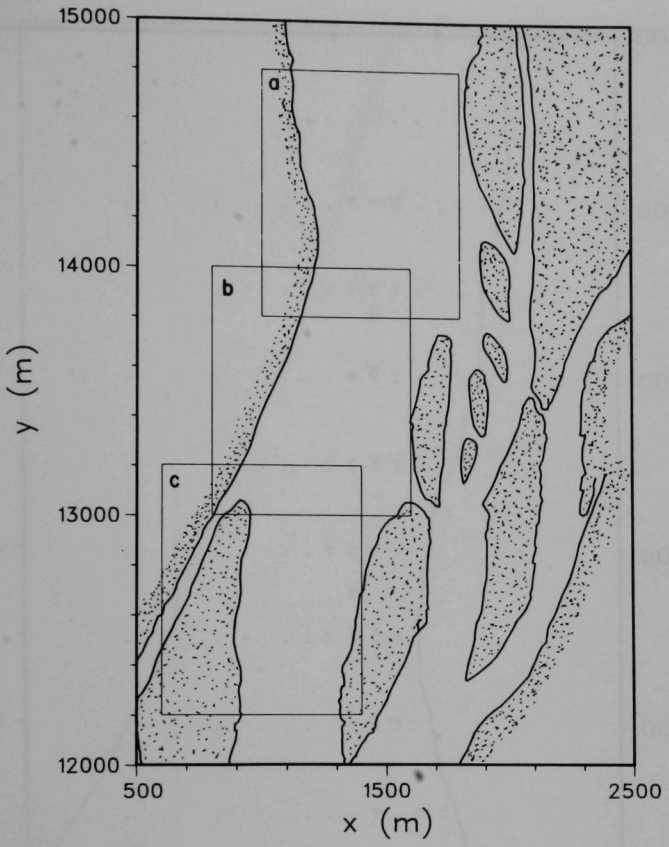

FIGURE B.12 Whitney Island Site Showing the Three Regions (a, b, and c) where Bottom Samples Were Obtained

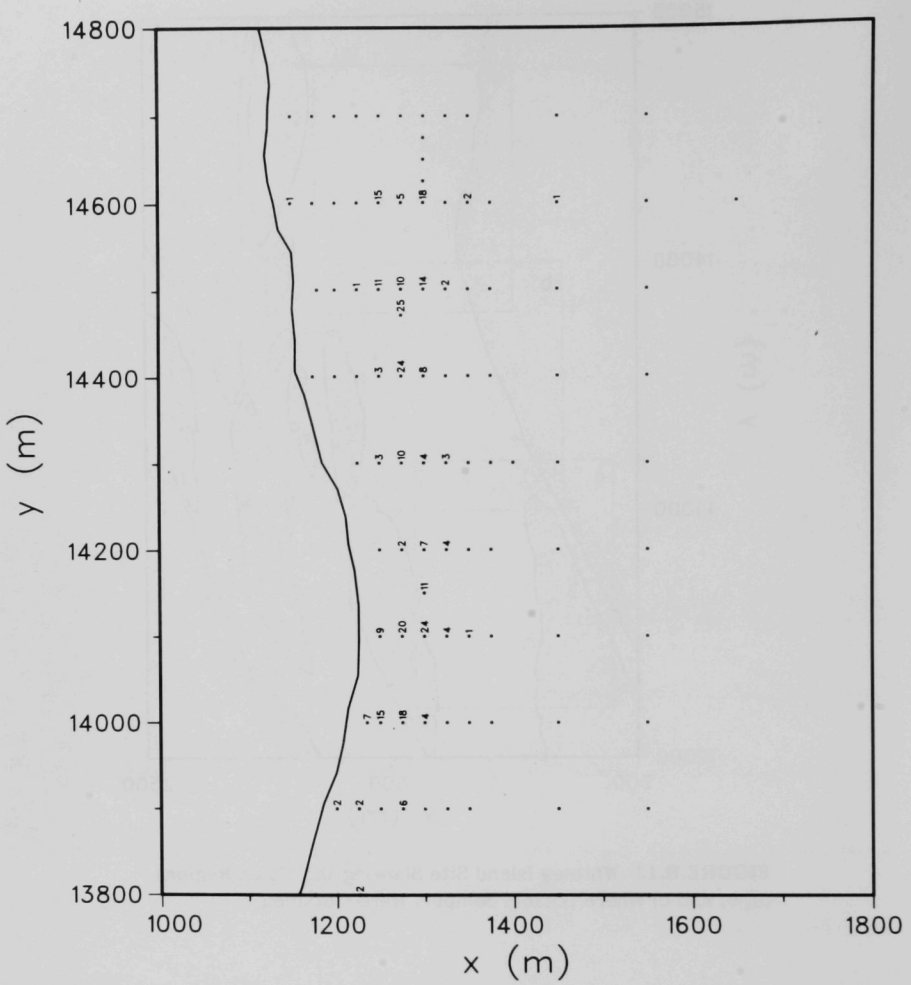

FIGURE B.13 Bottom Sampling Locations and Dyed Sand Counts in Region a of the Whitney Island Site for Survey I

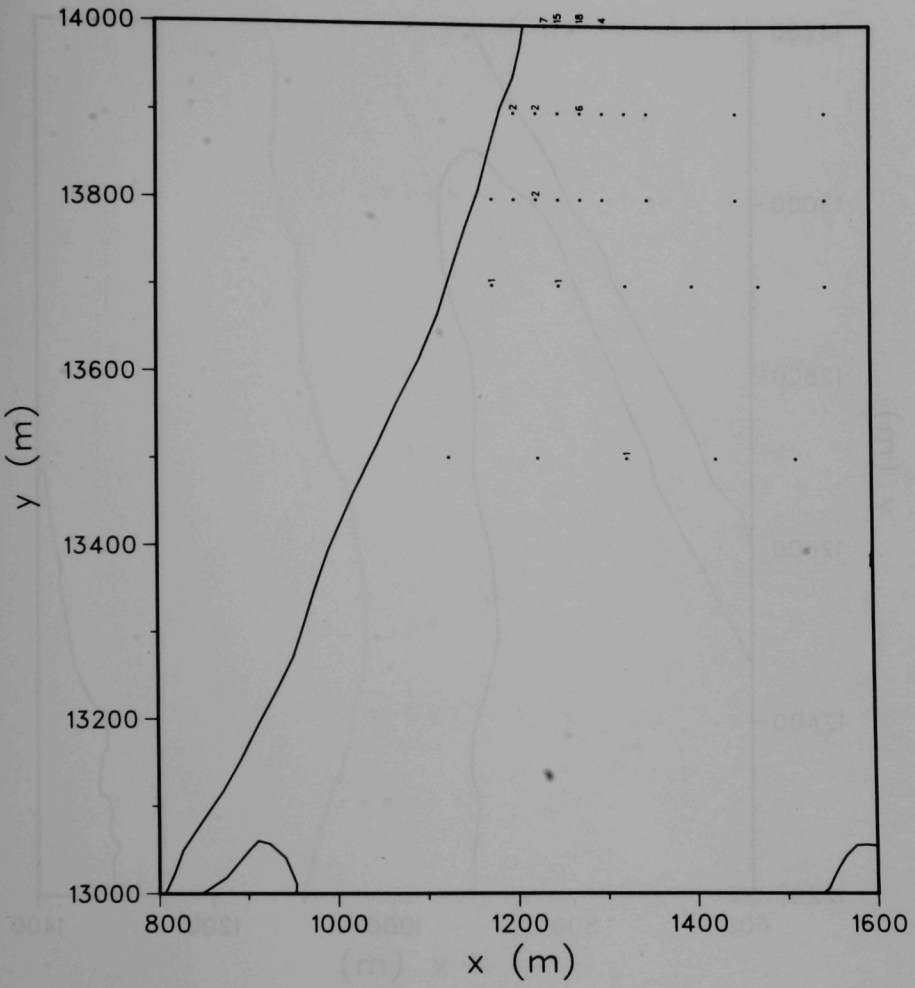

FIGURE B.14 Bottom Sampling Locations and Dyed Sand Counts in Region b of the Whitney Island Site for Survey I

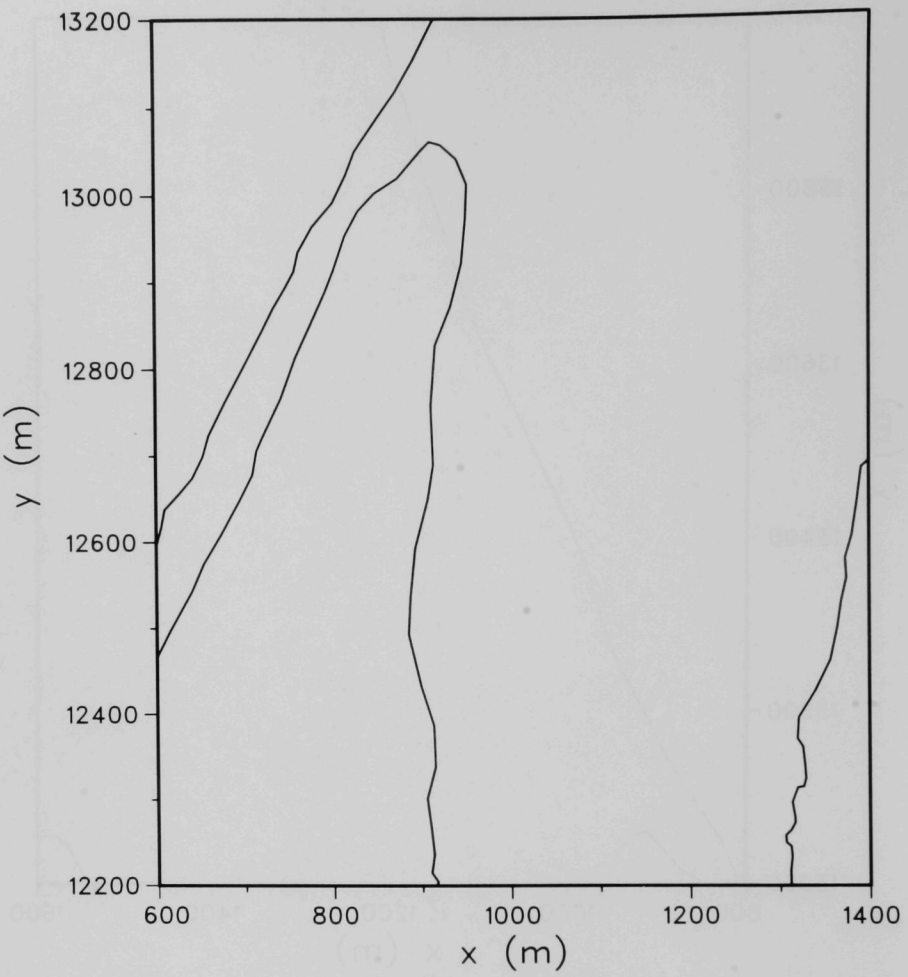

FIGURE B.15 Bottom Sampling Locations and Dyed Sand Counts in Region c of the Whitney Island Site for Survey I

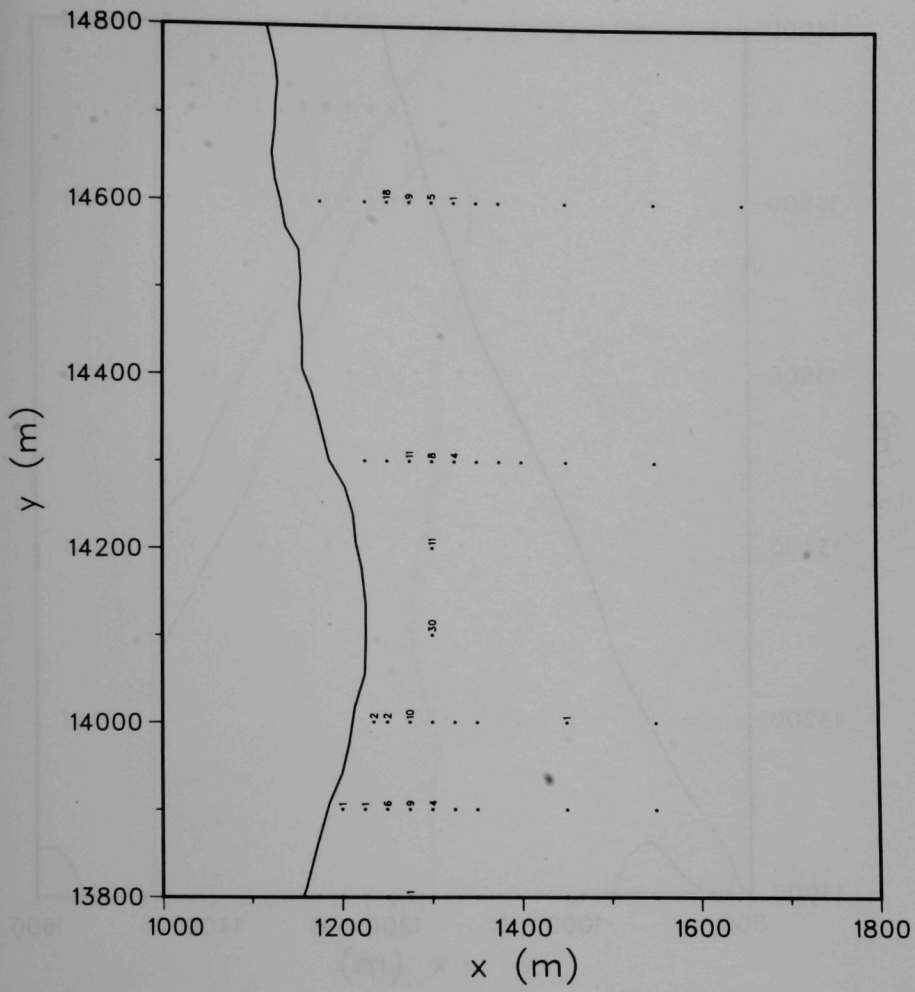

FIGURE B.16 Bottom Sampling Locations and Dyed Sand Counts in Region a of the Whitney Island Site for Survey II

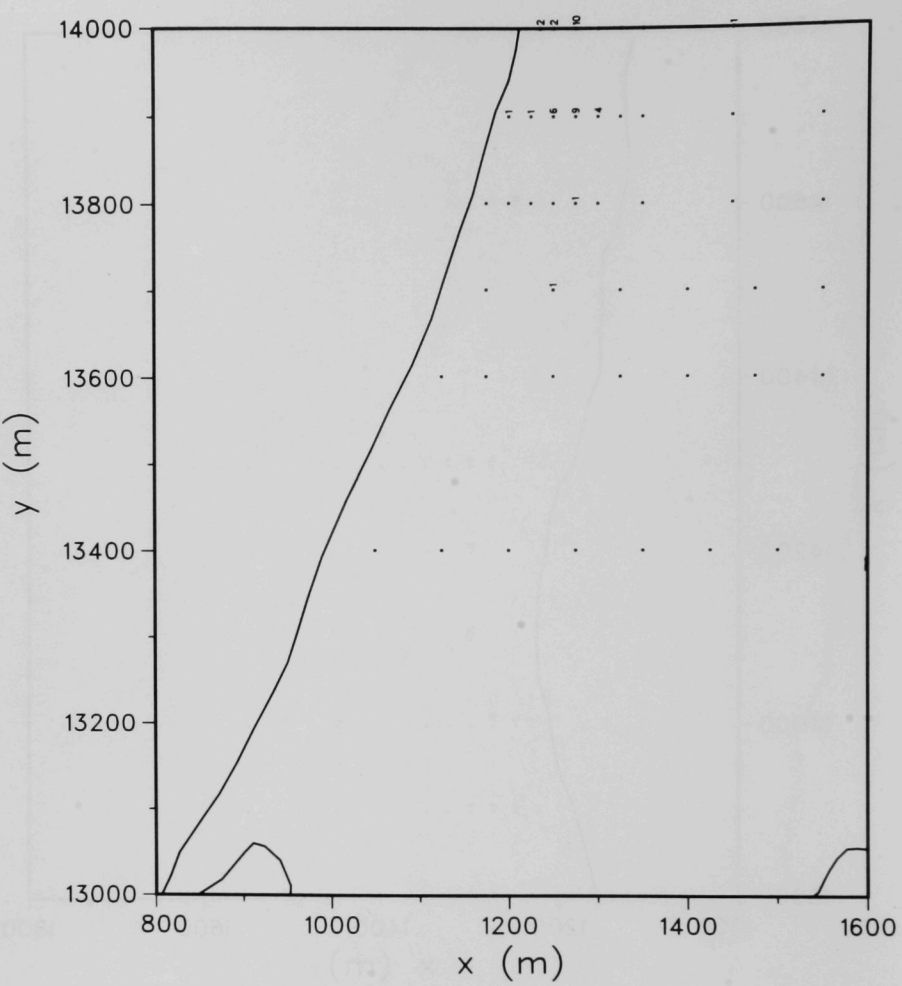

FIGURE B.17 Bottom Sampling Locations and Dyed Sand Counts in Region b of the Whitney Island Site for Survey II

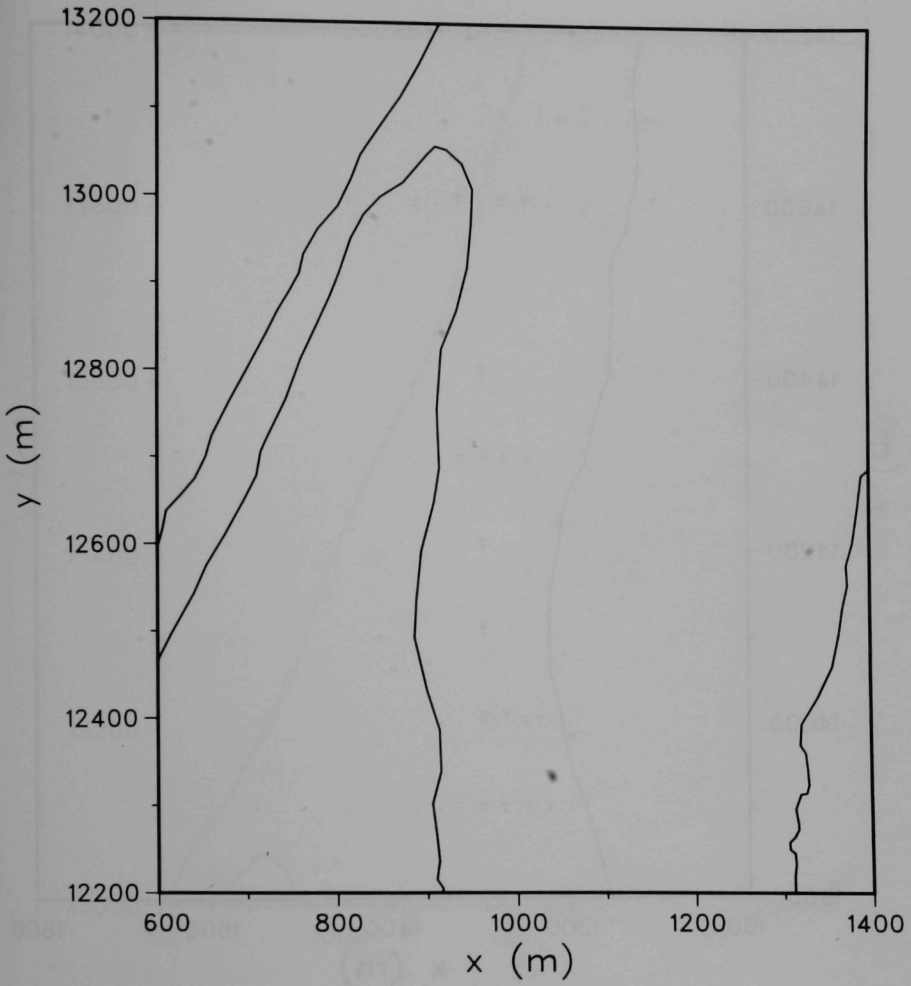

FIGURE B.18 Bottom Sampling Locations and Dyed Sand Counts in Region c of the Whitney Island Site for Survey II

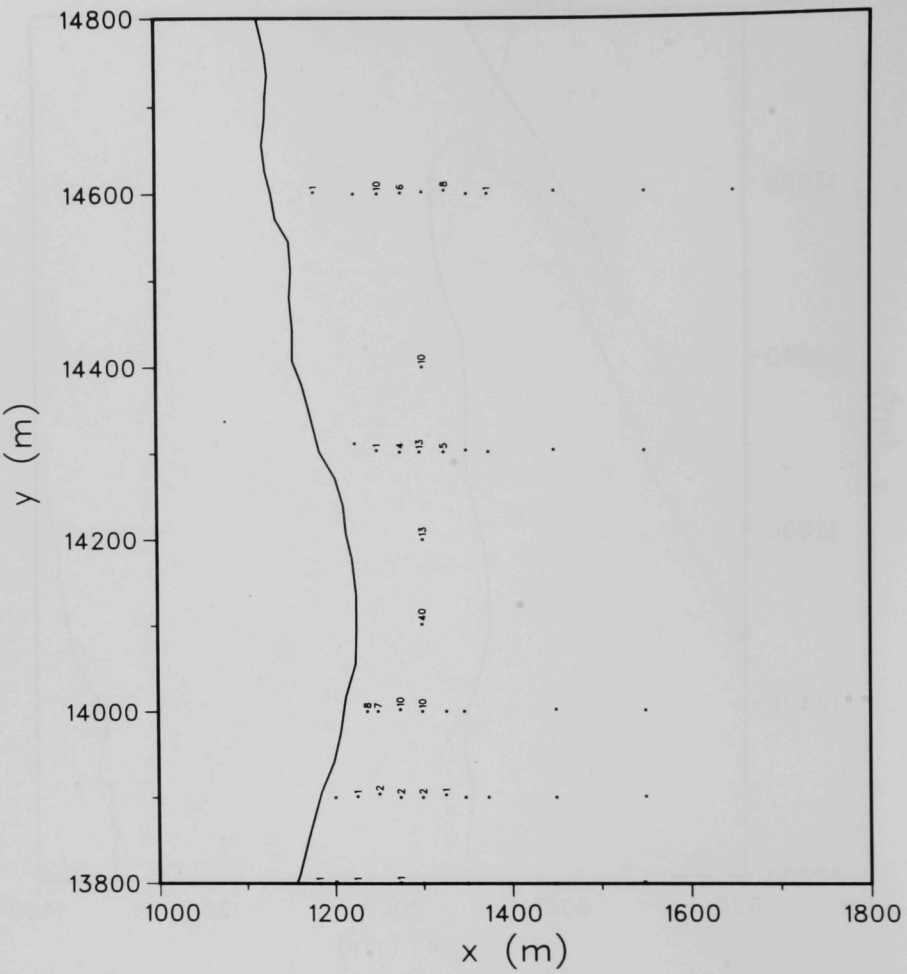

FIGURE B.19 Bottom Sampling Locations and Dyed Sand Counts in Region a of the Whitney Island Site for Survey III

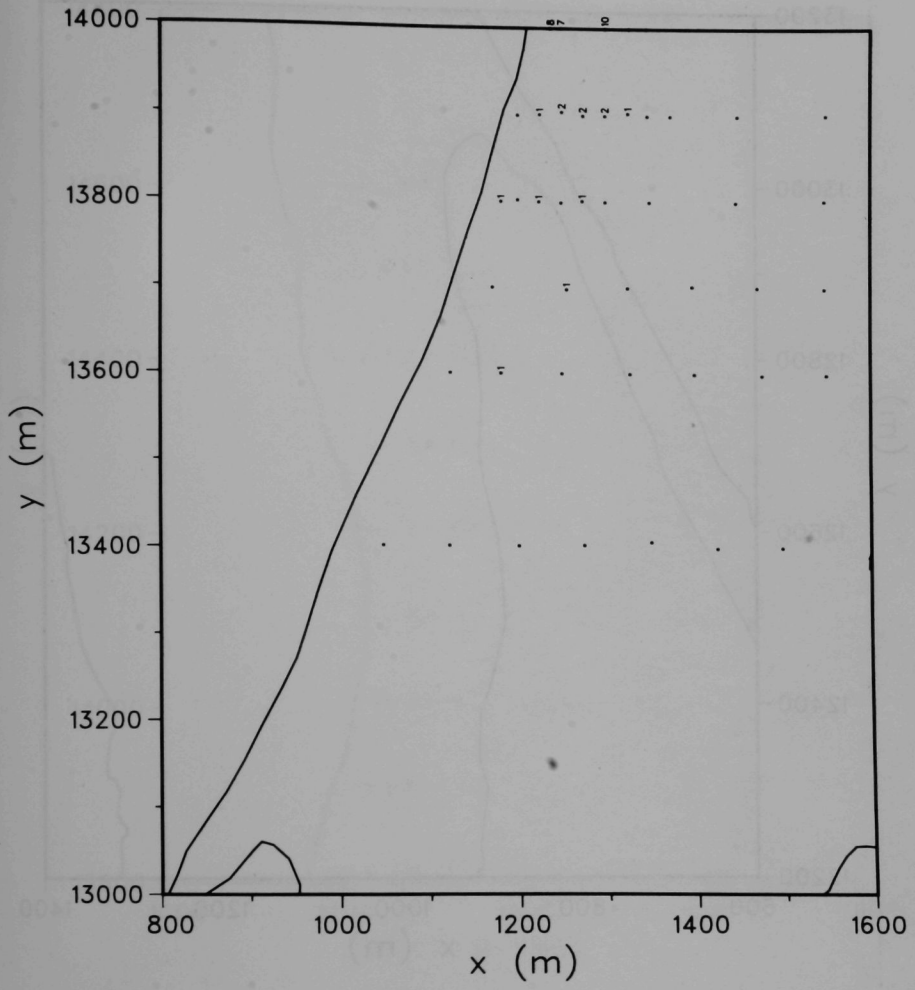

FIGURE B.20 Bottom Sampling Locations and Dyed Sand Counts in Region b of the Whitney Island Site for Survey III

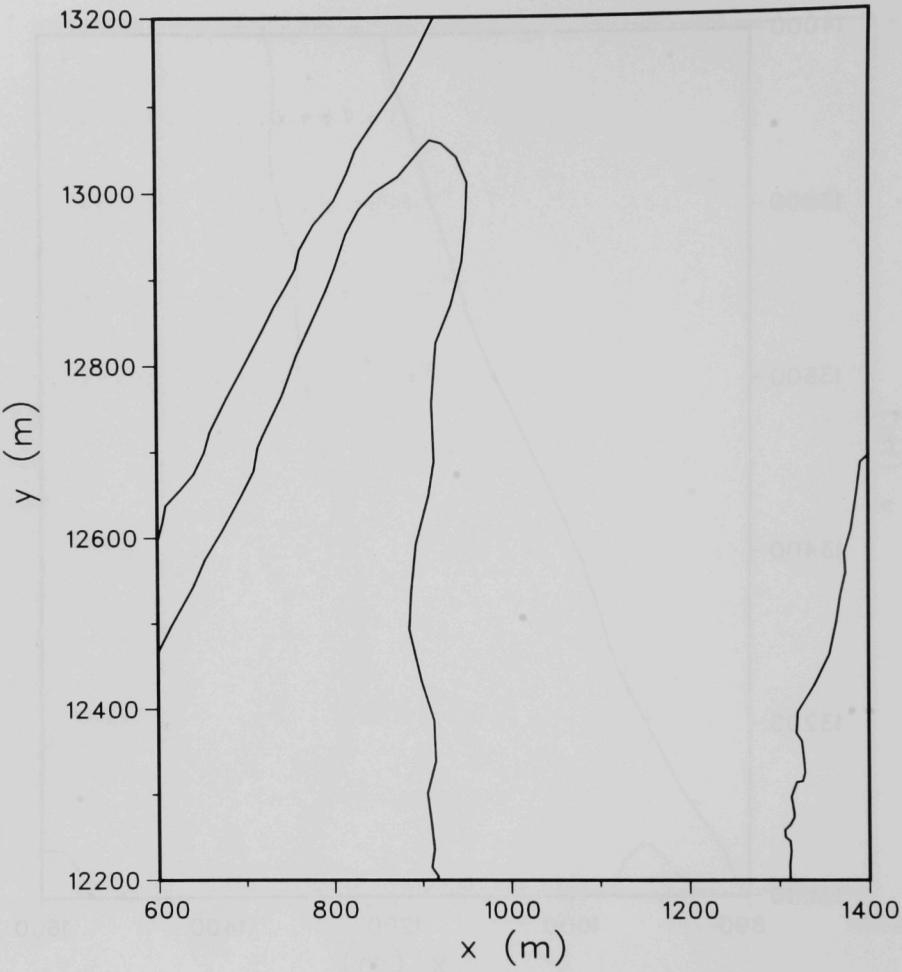

FIGURE B.21 Bottom Sampling Locations and Dyed Sand Counts in Region c of the Whitney Island Site for Survey III

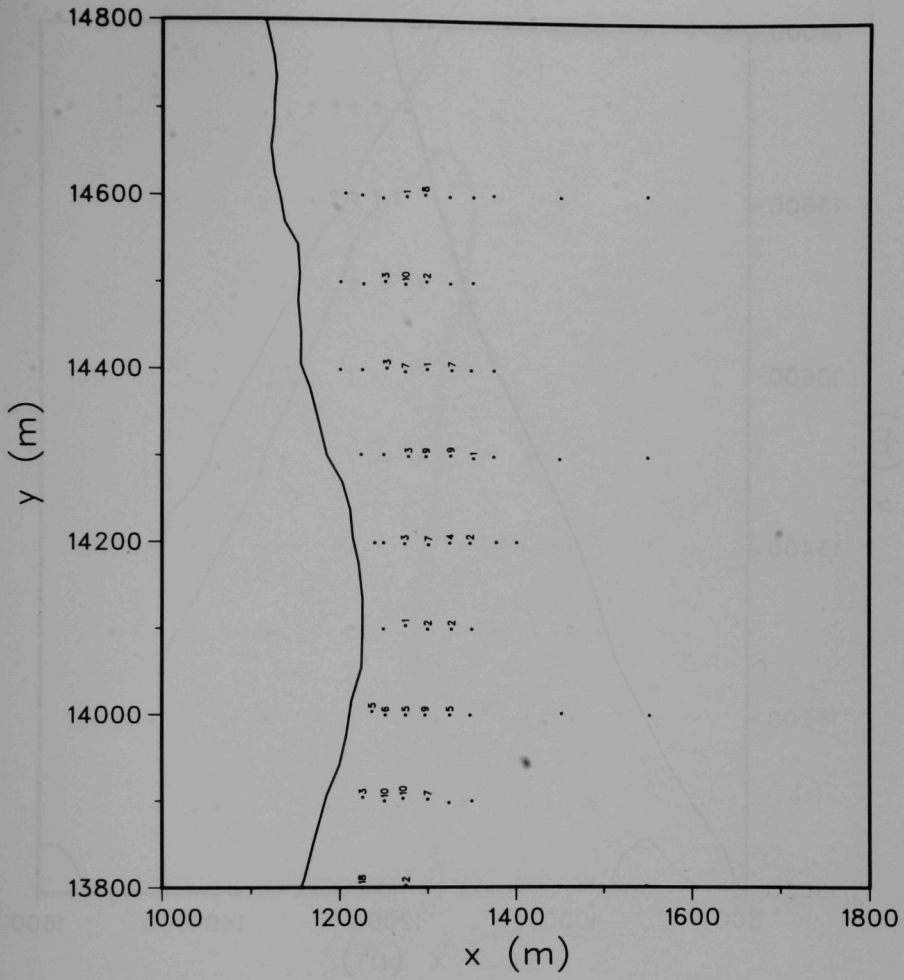

FIGURE B.22 Bottom Sampling Locations and Dyed Sand Counts in Region a of the Whitney Island Site for Survey IV

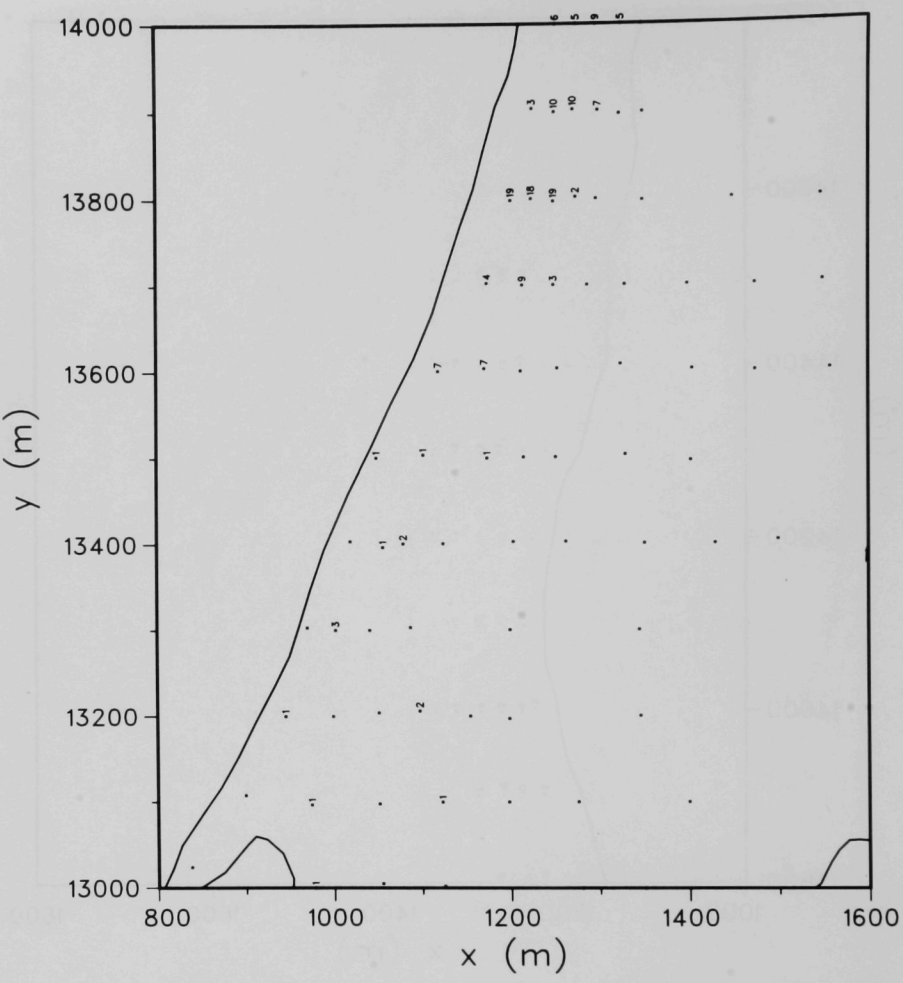

FIGURE B.23 Bottom Sampling Locations and Dyed Sand Counts in Region b of the Whitney Island Site for Survey IV

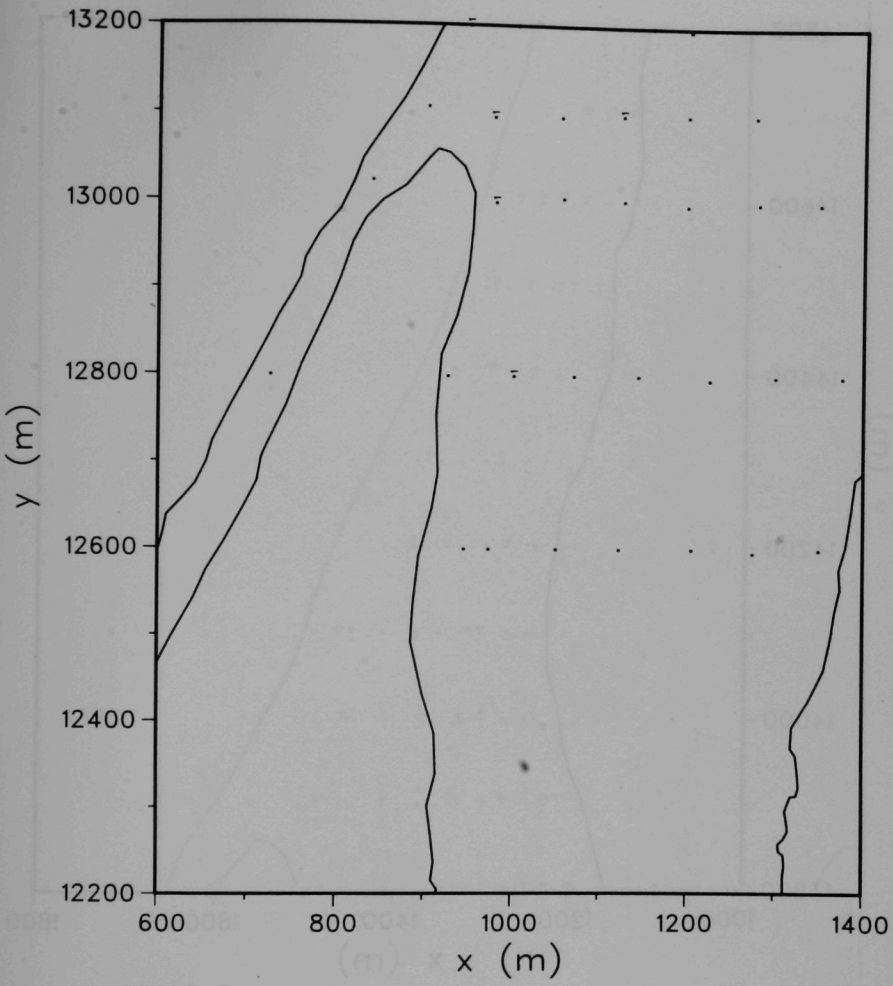

FIGURE B.24 Bottom Sampling Locations and Dyed Sand Counts in Region c of the Whitney Island Site for Survey IV

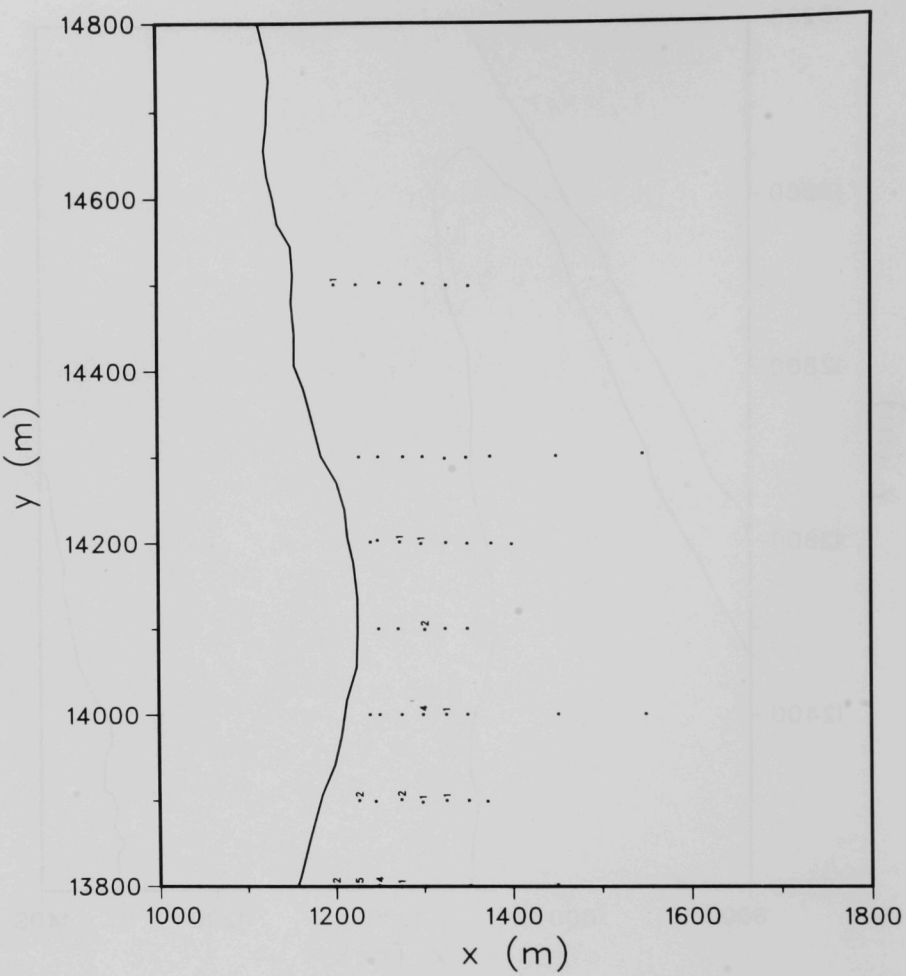

FIGURE B.25 Bottom Sampling Locations and Dyed Sand Counts in Region a of the Whitney Island Site for Survey V

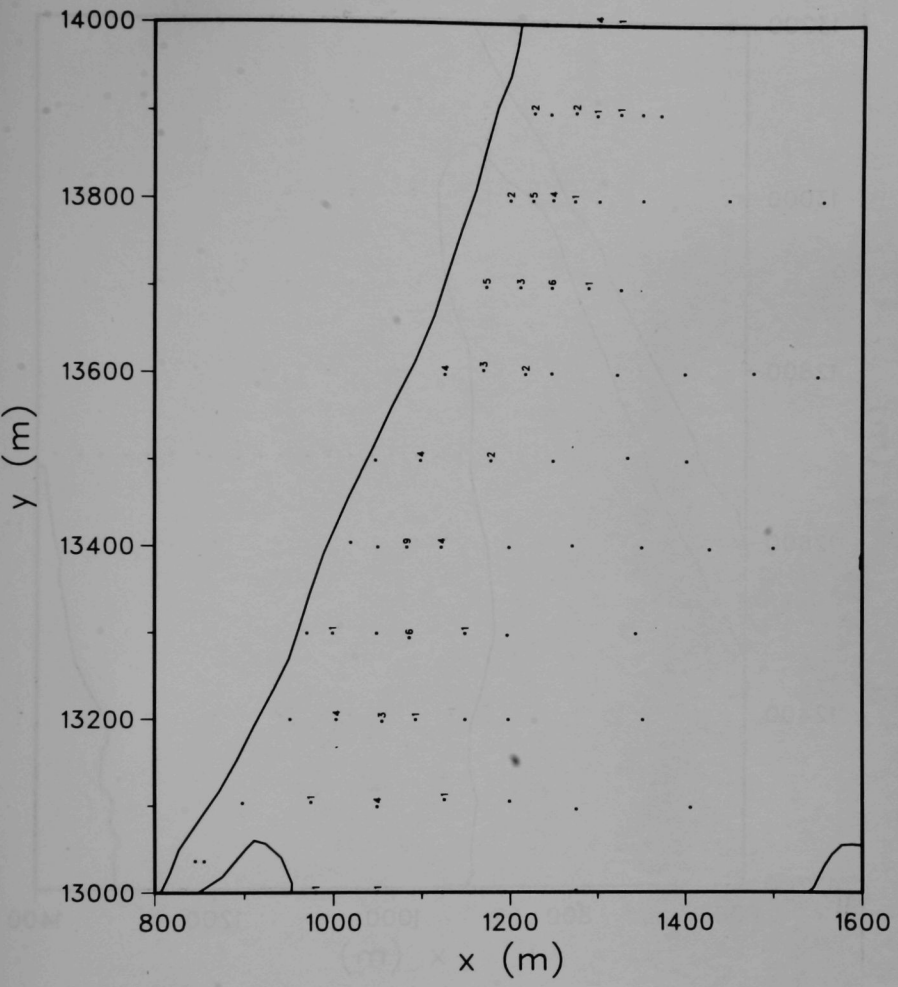

FIGURE B.26 Bottom Sampling Locations and Dyed Sand Counts in Region b of the Whitney Island Site for Survey V

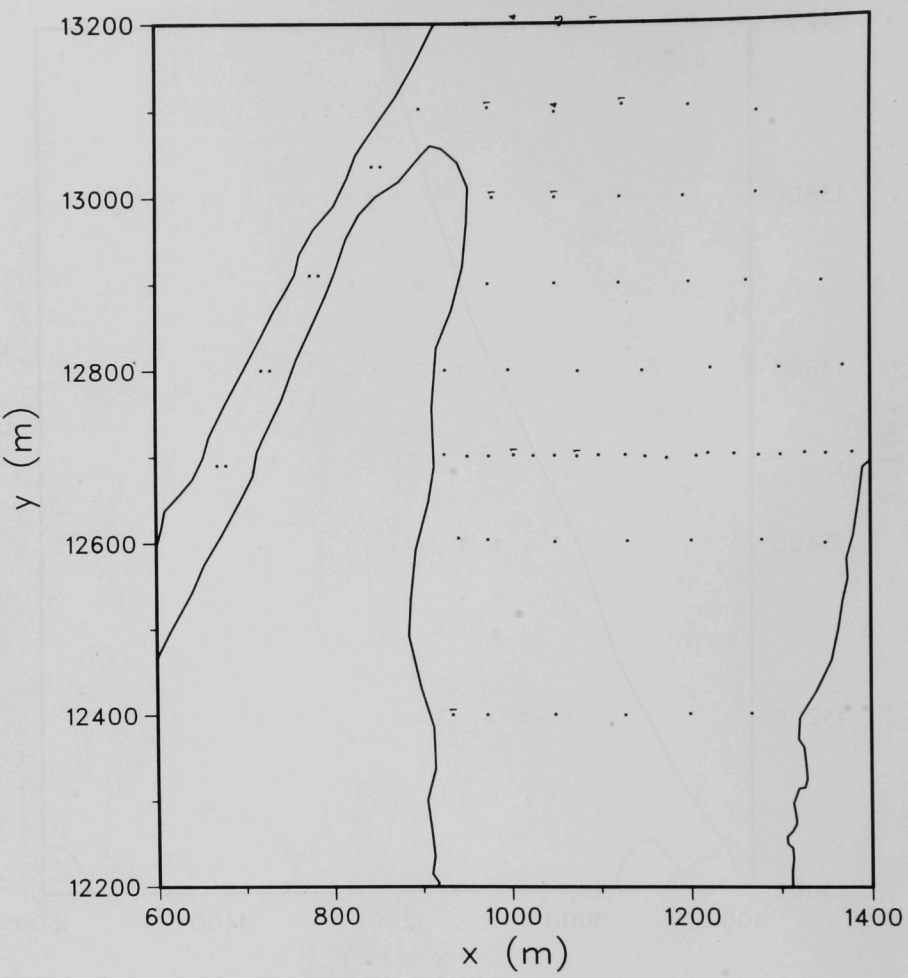

FIGURE B.27 Bottom Sampling Locations and Dyed Sand Counts in Region c of the Whitney Island Site for Survey V